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BY

EVAN W. SMALL

M.A. (CANTAB.) B.SC. (LOND.); F.G.S.
SOMETIME UNIVERSITY LOCAL LECTURER IN CHEMISTRY AND GEOLOGY

WITH 71 ILLUSTRATIONS

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PREFACE

THIS little volume contains the substance of a course of lectures delivered in various centres during the winters of 1884-1890. It differs from many of the smaller works on Physiography in that it is not a text-book arranged to meet the wants of students preparing for any special examination, and from most of the larger works in that it does not attempt to cover so wide a field. The lectures were originally designed to precede a course on geology, but it is hoped that the book may also serve as introduction to the study of other branches of science.

It is primarily intended for the "general reader," who wishes to acquire a certain amount of knowledge—accurate and definite so far as it goes—of the more striking phenomena of the earth; more detailed information on certain subjects is however added in the form of tables, which represent to some extent the more specialised work of the *class* as distinct from the *lecture*, in the University Extension method of teaching.

The list of lantern slides given in the appendix will probably be of use to teachers who may use the book.

In addition to the works mentioned in the references for further reading given at the end of each section, use has been made of that excellent compendium of universal information—"Chambers's Encyclopædia," and useful suggestions have been derived from the lecture syllabuses of former colleagues, especially those of Drs. R. D. Roberts, C. M. Thompson, W. Garnett, W. J. Sollas, and J. D. M'Clure.

I am indebted to Prof. V. B. Lewes, and Mr. V. B. Sells, M.A., for permission to use figures from companion volumes in this series, and to Mr. R. E. Steel, M.A., for the use of some of the illustrations of his "World of Science."

In conclusion I beg to express my thanks to my friends, Mr. F. T. Howard, B.A., and Mr. J. A. Crawley, M.A., for numerous suggestions, and for help in reading the proofs and compiling the index.

E. W. S.

NEWPORT, MON., *August, 1893.*

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THE EARTH

CHAPTER I.

INTRODUCTORY.

1. **The Method of Science.**—The word SCIENCE means *knowledge;* and it is the aim of the student of science to know as much as is possible about the great world of Nature around him. In early times men had little accurate knowledge about Nature; their ideas were, for the most part, vague and fanciful. As we trace the progress of any branch of natural knowledge, we find that these ideas become more and more exact and definite. It is to this definite and exact kind of knowledge about things that we give the name Science. Scientific knowledge, then, differs from ordinary knowledge in that it aims at being more accurate. Thus, the notion that science and common-sense are opposed to one another is a very erroneous one, for the method of science does not differ in kind from that by which we gain our knowledge of common things. Speaking generally, we may say that the successive steps of

what is sometimes called the "Scientific Method" are as follows: first of all comes the careful observation of phenomena (that is, the appearances of things); thus we establish a sure foundation of fact; then we seek by a comparison of the facts, to frame some theory which connects them together, and to establish some general truth of which the facts are only special instances. Before, however, we can consider our theory to be true, we must test it by a further appeal to observation and experiment. It will be easily seen that the value of such generalisations will largely depend upon the number and the accuracy of the observations and experiments on which they are based. Now it is not always easy to observe things really accurately. Our senses are sometimes actually misleading. When a schoolboy rapidly whirls a glowing splinter of wood, he seems to see a complete circle of fire, whereas, in reality, at any given instant the glow can be in one spot only. In such cases we gradually learn, by the use of our reasoning powers, to control our observations, and to distinguish between the false and the true. At the very best, however, our senses are imperfect in their indications, their power is limited to a comparatively small portion of the infinite variety of external phenomena, and we therefore seek to add, as far as possible, to their powers, by the use of artificial contrivances. Thus, the invention of such instruments as the telescope, the microscope, the spectroscope, and the photographic camera, have extended the range of our senses so as to enable us to make observations of things that, without these instruments, would be wholly beyond our powers of observation. Even with the aid of the best instruments our observations will still be subject to errors due partly to the defects of the instruments and partly to the imperfections in the powers of the observer, and it must, therefore, be the constant endeavour of the student of science to detect and to make allowance for these errors.

But supposing our observations to be quite trustworthy, we must be likewise cautious and accurate in our reasoning. There must be in science no such rash formation of sweeping generalisations, based upon a few isolated facts, as too often leads us, in our ordinary affairs, to form erroneous judgments about things. Hence it is, that, apart from the actual knowledge acquired, the study of any branch of science, especially if we aim at learning not merely results but the way in which those results have been obtained, may benefit us in our every-day life, by training us in more correct habits of thought and of observation.

2. **Classification of the Sciences.**—As the knowledge of Nature advanced and the number of observed facts increased, it became necessary for men to devote themselves more especially to certain classes of facts; and so the study of science has been divided into many departments, or branches. Thus ASTRONOMY (Greek, *astron*—star, and *nomos*—law) is the branch of science that is concerned with the forms and relations of the sun, planets, stars, and other heavenly bodies; GEOGRAPHY and GEOLOGY (Greek, *ge*—the earth) treat of our earth, its present aspects and past history; CHEMISTRY is the branch of science which deals with the composition of bodies; PHYSICS (Greek, *phusikos*—natural) is the term now generally used to include the subjects of dynamics, heat, light, electricity, etc., which treat of the nature and relations of the various forces and energies of nature; BIOLOGY (Greek, *bios*—life) deals with the life of the world, both animal (*Zoology*) and vegetable (*Botany*). Some of these departments of science have been studied from very early times; others are much more modern. Astronomy is one of the most ancient of the sciences, for in

the very first stages of civilisation, men had begun to observe such phenomena as the rising and setting of the sun, the alternations of the seasons, and the phases of the moon; while no great amount of intelligence was required to arrange the stars which stud the firmament into various artificial groups, or constellations. In its earlier stages, however, astronomy was very much mixed up with astrology, the pretended art of divining future events by observing the stars or planets. So also chemistry was in early times associated with various magic arts, the early chemists, or alchemists, as they were then called (probably from an Arabic word signifying the "black art"), being chiefly concerned in the search for the "philosopher's stone," which was to convert everything into gold, and in somewhat later times for the "Elixir vitæ," or Elixir of Life (Arabic, *El iksir*—the philosopher's stone), which would, it was thought, confer immortality, or, at least, great length of life, and make the old young again. Many of the departments of physics, such as electricity and magnetism, are essentially modern sciences, and so (as we shall see later) is geology.

The present work does not deal fully with any one of these various branches of science, but is intended to serve as an introduction to them all. It treats of some of the more striking phenomena of the earth, beginning with its astronomical relations, then dealing with the materials of which it is constructed, including the composition of its solid crust or lithosphere, of the atmosphere, or ocean of air surrounding it, and of the terrestrial waters, or hydrosphere. Next, the laws of energy are discussed, and afterwards the past history of the earth, as partially revealed to us by its present aspects, is touched upon. Such a general exposition of the facts and laws of Nature constitutes what Huxley (adopting a term formerly used for a branch of mineralogy) has termed Physiography, a description of Nature. The Germans call it "Physische Erdkunde"—physical earth-lore.

3. Physical Measurements.—In seeking to gain accurate knowledge of the phenomena constantly taking place around us, we require to make various measurements. Now it is found that all other measurements may be expressed in terms of three fundamental units, *viz.*, those of *time*, *length* (*i.e.*, space of one dimension) and *mass*: all of these being quantities which cannot be defined in terms of anything simpler than themselves. Time and space we can *conceive of* as existing apart from matter, but in practice we can only estimate time by the motion of bodies, and space by its relation to the place of material substances.

The unit of **time** adopted for scientific purposes is the *second* of mean solar time, or the $\frac{1}{86400}$th part of the average length of a solar day—*i.e.*, the average for the year of the intervals that elapse between two successive occasions on which the sun crosses the meridian, or is due south of a place.

All our clocks and watches are supposed to keep mean solar time. By means of the chronoscope (an instrument which may be regarded as a microscope for time) we are able to sub-divide time to the thousandth part of a second.

The unit of **length** in most common use in this country is the *foot*, which is one-third of the British standard yard, defined by law as, "the distance between the centres of the transverse lines in the two gold plugs in the bronze bar deposited at the office of the Exchequer," this distance being measured at the temperature of 62 degrees of the Fahrenheit thermometer. The metric unit of length is the *metre*, which was defined in 1795 as the distance, at the temperature of melting ice, between the ends of a platinum bar made by Borda, and preserved in the Archives at Paris. It is equal to about 39·37 English inches (3 feet 3$\frac{3}{8}$ inches), and was originally intended to be the 10-millionth part of the distance from the equator to the pole, but it is really slightly less than this. The metre is sub-divided into 10 decimetres, 100 centimetres, and 1,000 millimetres. A millimetre is very nearly equal to the 25th part of an inch. The kilometre (1,000 metres) = 0·6273 of an English mile, or roughly, 8 kilometres = 5 miles. In measuring *surfaces* (*i.e.*, spaces of two dimensions—length and breadth) and *volumes* (which occupy space of three dimensions, having length, breadth and thickness) we use units derived from the fundamental unit of length. In the metric system the unit of volume is the *cubic centimetre*—*i.e.*, a cube whose side is one square centimetre.

A *litre* (the ordinary measure of capacity), or cubic decimetre, contains 1,000 cubic centimetres (written c.cm.) and equals 1·76 pints, or 61·03 cubic inches.

The British unit of **mass**, or quantity of matter, is the imperial standard *pound*;—a piece of platinum preserved in the office of the Exchequer, and defined by Act of Parliament as the only standard of weight.

The *weight* of a substance, however, varies in different latitudes and at different heights above the ground (being greater near the pole than at the equator), whilst the *mass or quantity of matter* in it remains the same. Hence the pound ought really to be regarded as the unit of mass, not of weight: inasmuch, however, as, under ordinary circumstances, two equal masses counterpoise one another in a balance, we usually compare masses by their weights. The French standard of mass is the *kilogramme* (about 2$\frac{1}{5}$ lbs.), but the unit generally adopted for scientific purposes is the *gramme*, which is approximately the mass of one cubic centimetre of water at the temperature of 3·90 C., and equals about 15·4323 English grains. All measurements expressed in terms of the three fundamental units of Time, Space and Mass, are said to be in absolute measure; and the system of absolute measurements, based on the centimetre gramme and second, is called the C. G. S. system of units.

The science which deals with space merely without introducing the notion of time is GEOMETRY. The word literally means land measurement, and amongst the ancient Egyptians with whom the science originated, it was confined almost exclusively to the practice of surveying. The consideration of space and time together constitutes KINEMATICS (Greek, *kineo*—I move) or the science of pure motion. In KINETICS we introduce the idea of mass and consider the motion of actual material bodies. The term DYNAMICS (*dunamis*, force) is usually, though inaccurately, regarded as including both kinematics and kinetics.

The rate at which a body moves or changes its position relatively to other bodies is termed its **velocity**,[1] and a body is said to move with unit velocity when it moves a unit of length in a unit of time. When the velocity is not uniform its rate of change is termed **acceleration**, and the unit of acceleration is that of a body whose velocity is increased or diminished by the unit of velocity in the unit of time. In the C. G. S. system, the unit of velocity is that of a body which moves through a distance of a centimetre in a second, and the unit of acceleration is that of a body which has its velocity increased (or diminished) by one such unit of velocity every second.

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[1] The term velocity is usually understood to include both the distance travelled in a given time and the direction of motion. The term speed applies to rate of motion without taking direction into account.

References.—Chisholm, *Weighing and Measuring* (Nature Series. Macmillan).
Glazebrook, *The Laws and Properties of Matter*, ch. i. and ii. (Modern Science Series. Kegan Paul).
Clerk Maxwell, *Matter and Motion* (S.P.C.K.).
Garnett, *Mechanics* (S.P.C.K.).

CHAPTER II.

THE EARTH AS A PLANET.

Section I.—The Form and Movements of the Earth.

1. **How the Earth's Shape and Size are determined.**—As a simple instance of the application of the scientific method, let us consider some of the grounds of our knowledge as to the shape of the earth. The ancients regarded the earth as a more or less flat disc, but facts were little by little observed that would not accord with this view. A ship at sea, for example, sailing away from an observer on shore, disappears gradually; first, the hull sinks from sight, then the lower masts, and, finally, the topmasts disappear. Again the horizon, or line along which the earth appears to meet the sky, as seen by an observer at sea or on a great plain, appears circular, and the circle enlarges as we ascend from the earth's surface. Such facts as these cannot be well explained on the supposition that the earth is a flat plain: but from our knowledge of the properties of bodies, that are round like a ball, we see that such a body would give the appearances observed. From this generalisation (or *induction*) various special conclusions (or *deductions*) have

been drawn, and these, on being tested by an appeal to observation, have always proved to be true. Thus we know, by experiment, that a sphere always gives a circular shadow, hence if we could observe the shadow of the earth, it should appear circular. Now, we can observe this shadow in eclipses of the moon, and it is always then found that the part of the earth's shadow, which is seen, is an arc of a circle. Again, if the earth be spherical, it should be possible to travel completely round it by always moving in one direction. Since the time of Magellan, who first sailed round the world, the earth has constantly been circumnavigated by vessels steering constantly in an easterly or westerly direction. In these, and in other ways, our generalisation, as to the shape of the earth, is verified.

Before considering how the size of this great ball can be determined, it will be useful to briefly explain the method adopted for indicating the exact positions of places on the earth's surface.

For this purpose we imagine the surface to be covered with a number of circles (Fig. 1). Lines drawn due N. and S. through any place are termed meridians or lines of **longitude**, (Latin, *meridies*—mid-day—so called, because when the sun reaches the meridian of any place, he is at his highest point in the heavens for that day, for that place). Each meridian forms a semicircle stretching from pole to pole, and two opposite meridians meet to form a *great circle* of the globe, *i.e.*, a circle dividing it into two equal parts or hemispheres. The great circle drawn at right angles to the meridians, midway between the poles, is called the **equator**, and small circles drawn parallel to the equator are known as **parallels** of latitude. The **longitude** of any place is the *angular distance* of its meridian E. or W. from some standard or zero meridian (usually the meridian of Greenwich).

The term, angular distance, may, perhaps, be best explained by a rough illustration. Suppose an observer, situated at some distance from two objects A and B (say trees or spires), to apply the hinge of a pair of compasses to one eye, and to open out the compasses until one leg points directly towards A, and the other towards B, then the angle between the two legs—measured in degrees and parts thereof (a degree being $\frac{1}{90}$ of a right angle)—is the angular distance between A and B as seen from the position of the observer; it will readily be seen that this distance will increase as he approaches, and lessen as he recedes from A and B. In practice, instruments more delicate than ordinary compasses would have to be used. Now, imagine the compasses to be at the earth's centre, and to be opened out in the plane of the equator—the two legs pointing respectively to the prime and to some other meridian, then their inclination to one another will be the angular distance between these two meridians. When we speak of the *length* of a degree of latitude we refer to the length of the arc of parallel included between two meridians which are 1° apart. Since all the angles, made by any number of straight lines meeting at a point, are equal to 4 right angles, and since the earth makes a complete rotation on its axis (page 18) once in 24 hours, it follows that the earth turns through 1° every 4 minutes; hence the longitude of a place can be reckoned by observing the difference between local and Greenwich time; thus when it is 12 o'clock at Greenwich, it is 4 minutes to 12 at places 1° W. longitude, and 4 minutes past 12 at places 1° E. longitude.

The **latitude** of any point on the earth's surface is its angular distance N. or S. of the equator, thus the latitude of the point P (Fig. 1) is the angle P O M (in this case $23\frac{1}{2}$°) at the centre of the earth, subtended by the arc of meridian

P M. The latitude of a point on the equator is, therefore, 0°; while the poles are 90° N. and S. latitude respectively.

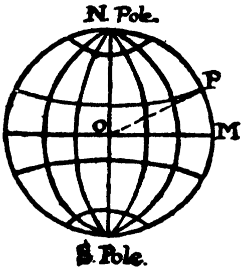

Fig. 1.

Now, an observer situated at any place on the equator would see a point in the heavens known as the pole (which may be roughly regarded as coincident with the star α in the constellation of Ursa Minor, known as the pole star) on the horizon. If he were to travel 1° on a meridian towards the north, the pole star would appear to be elevated 1° above the horizon; by travelling 2°, the pole star would appear elevated 2°, and so on, until on reaching the North Pole, the pole star would appear to be in his zenith or immediately overhead, *i.e.*, at 90° from the horizon. Hence it will be seen that the *latitude of a place is always equal to the observed elevation of the pole star above the horizon.* Thus it is easy to determine astronomically a DEGREE OF LATITUDE, that is the length of the arc of meridian, such that the difference of latitude, between its two ends, is one degree. If now this length can be measured in ordinary lineal units, feet or yards, the whole circumference of the globe (regarded as a perfect sphere) will be obtained by multiplying this length by 360, the total number of degrees in the circumference of a circle. This actual measurement of an arc of meridian can be very accurately done by the method of **triangulation**, the general principle of which is as follows:—In the first place a BASE LINE has to be selected on some firm level piece of ground, and its length accurately measured by means of metal rods (usually constructed of two different metals arranged in such a way that their unequal expansions, due to changes of temperature, neutralise one another, as it were, so that the distance between two marks remains constant). The intervals between the rods (which are not allowed to touch one another) are measured by means of microscopes. Such a base line, employed in the Ordnance Survey of Great Britain, was that measured along the border of Lough Foyle in Ireland, its length being about 8 miles. The base line A B (Fig. 2) being measured, some prominent object which can be seen from both A and B is selected, and the angles B A C, A B C carefully measured by means of a theodolite. Knowing the length of A B, and the size of these angles, we can calculate, by trigonometry, the lengths A C and B C. These may then be used to form the bases of other triangles as B C D, A C E, whose remaining sides are similarly determined; thus the whole country may be covered with a net-work of such measured triangles, and by this means the distance between two remote stations situated on the same meridian can be accurately determined. In the Ordnance Survey of the United Kingdom 250 *trigonometrical stations* were employed, and it was found possible, by using the lime-light at night, to employ triangles whose sides were as much as 60 or 80 miles in length. On the completion of the survey, the length of the base line, that had been measured on the shores of Lough Foyle, was calculated by means of a series of triangles, starting from another base, measured on Salisbury Plain (360 miles away). The length thus found by calculation did not differ by much more than

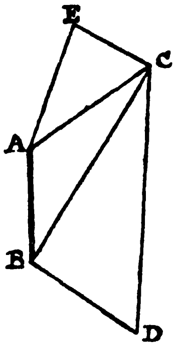

Fig. 2.

5 inches from the length as obtained by direct measurement. Similar surveys have been made in various parts of the world, and in this way the length of a degree of latitude has been determined in several places, with the result that this length is found to be greater towards the North and South Poles than it is near the equator. At the equator it is 362,746·4 feet, and at the pole (as calculated from observation in high latitudes), 366,479·8 feet. This shows that the earth is not a perfect sphere, but is flattened at the poles, and bulges in the equatorial regions, the polar diameter being 7899·6 miles, and the equatorial 7926·6 miles, or 27 miles longer. The polar diameter is thus about $\frac{1}{293}$ shorter than the equatorial. Such a figure is known as an ellipsoid or *oblate spheroid* of revolution; but further accurate measurements of degrees of longitude in equatorial regions have shown that the equator is not really a perfect circle, so that the figure of the earth is not a true ellipsoid.

2. **The Apparent Movements of the Heavenly Bodies.**—When we look out upon a clear night and watch the starry heavens, we notice that many of the stars appear to rise in the east and set in the west, but that their position relative to one another does not appreciably change; that, in fact, the star-strewn dome of the heavens is apparently carried round just as if the stars were all fixed to the inside of a great hollow globe, which turned every day about an imaginary axis, passing nearly through the pole star (which seems to the unaided eye to remain fixed in the heavens) and the place of the observer. The *horizon* seems to be a great circle of this celestial globe. The SUN, too, seems to be carried round the earth from east to west; but while the stars, night after night, and year after year, retain their relative positions (hence the term "fixed stars"), the sun appears each day to be placed in a somewhat different position upon

the celestial sphere, moving apparently from west to east relatively to the stars, and getting back to the same position on the imaginary globe after a year's interval, so that while the stars appear to make 366 revolutions in a year, the sun makes only 365. The path of the sun among the fixed stars lies in a great circle of the celestial globe called the **Ecliptic**, which is inclined to the equator at an angle of 23° 27′, cutting it in two points called the *equinoctial* points.

The MOON, like the sun, while carried round from east to west every day with the star sphere, seems to move slowly among the stars in a contrary direction, so that for every 27 apparent revolutions of the stars, the moon makes only 26. In about $27\frac{1}{3}$ days she completes her circuit of the star sphere from west to east, moving nearly on a great circle of the globe inclined at about 5° to the ecliptic.

Besides the sun and moon there are other heavenly bodies, apparently stars, which do not keep a fixed position in the star vault. These are the PLANETS (*i.e.*, wanderers), five of which are visible to the unaided eye, *viz.*, Mercury, Venus, Mars, Jupiter, and Saturn. The planets seem to move on the whole eastward among the stars; sometimes, however, they become stationary, and again they retrograde or move from east to west.

Moreover, their retrograde motion is not quite on the same track as their motion of advance, and hence the apparent paths of the planets form a succession of loops as shown in Fig. 3, which represents a loop of Saturn's path. The number and size of these loops vary for different planets, thus Mercury makes three loops in his circuit of the heavens; Jupiter about eleven; Saturn nearly thirty. Venus goes round her

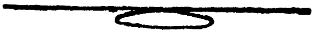

Fig. 3.

circuit more than once and a half times, and Mars more than once, between each successive loop. The planetary wanderings are confined to a *belt* of the heavens, extending about 8° on either side of the ecliptic, termed the *zodiac.* These apparent paths of the sun, moon, and planets were more or less correctly determined by the Chaldean astronomers, but they do not seem to have attempted to frame any theory of the causes of these movements. The Greek astronomers were the first to construct a mechanism of the heavens. They were convinced that beneath the seeming irregularity of the planetary wanderings there must be a real order, and taking uniform motion in a circle, as the basis of this order, they tried to account for all the celestial movements by superposing one circular motion upon another.

3. **The Theory of Epicycles.**—According to the Greek astronomers, the earth is a fixed sphere round which the celestial sphere rotates. In order, then, to account for the retrograde movements of the planets, they supposed that each planet moved as if attached to one end (A) of a rod A B (Fig. 4), which was turning uniformly about its other end (B) as a centre, this centre being again carried uniformly round in the same direction in a larger circle by being attached to one end of a longer rod, B C, revolving about its opposite end fixed at C. The effect of such conjoined motions will easily be seen to correspond with the kind of movement actually observed in the case of the planets. Thus it is clear that if A is being carried along more rapidly in its small circle (called the *epicycle*) than the point B carried round in the larger circle (called the *eccentric*) in

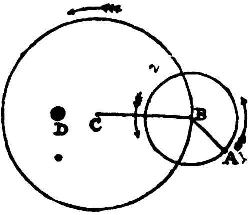

Fig. 4.

the same direction, then the planet as seen from the earth at D would seem to have a forward motion while moving in the outer portion of its small circle (as at 1), and a backward motion while moving in the inner portion (as at 2), while at some point between its advance and retrograde motions it must appear to be stationary. The shapes of the planetary loops were to some extent explained by the supposition that the plane of the epicycle was inclined to the plane of the eccentric. As observations of the planetary motions increased in accuracy, however, various small irregularities were detected, which had to be explained by adding on several smaller epicycles as well as by oscillations of the planes of revolution, until at length the system became extremely complex. The Greek astronomer, Ptolemy (about 130 A.D.), gathered up all that was then known of the science of astronomy in a great book, called by the Arabian astronomers the Almagest, and since it is from this work that our knowledge of Greek astronomy is mainly derived, the epicyclic theory is generally known as the PTOLEMAIC SYSTEM.

4. **The Copernican Theory.**—After the time of the ancient Greeks, the spirit of inquiry in Europe seems to have largely died out, and very little attention was given to the pursuit of scientific knowledge. The rise of modern science may be said to date from the astronomical discoveries of Copernik, Tycho Brahe, and Kepler, in the sixteenth and seventeenth centuries of our era. Copernik, or Copernicus (born at Thorn on the Vistula in 1472), at first took the Almagest as his text-book, but soon becoming dissatisfied with the great complexity of the Ptolemaic system, he gradually worked out a new system, which accounted for the strange apparent movements of the planets in a much simpler way than had been done before. He found that

some of the ancients had suggested that the movements of Venus and Mercury (which are distinguished from the other planets in that they are constantly seen to travel first to the right hand side of the sun, and then to the left, never being distant from the sun more than 48 and 20 degrees respectively), might be accounted for by supposing that the sun was in the centre of the epicycle of each, so that these planets travelled round the sun as it, according to the Ptolemaic system, travelled round the earth. It had also been suggested that the motion of the celestial globe might be only an apparent one due to a real rotation of the earth on an axis passing through its centre, and that the revolution of the sun round the earth might be an apparent motion due to a real revolution of the earth round the sun. In considering these suggestions of the ancient astronomers, Copernik at length framed a theory of the movements of the planets, the main principles of which may be thus stated :—(i.) *The daily rotation of the heavens is only an apparent motion caused by the rotation of the earth from west to east, about an axis passing through its centre.* Thus the diurnal rotation of the whole complex mechanism of the heavens is entirely done away with, and replaced by the

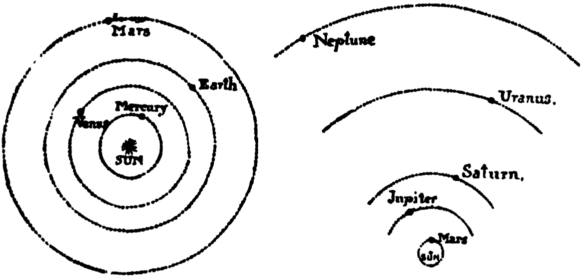

Fig. 5.

simpler rotation of the earth itself, which, it is easy to see, would give precisely the same appearances, just as in the case of a landscape observed from a railway train, the actual motion of the train in one direction gives rise to an apparent motion of the trees and other stationary objects in the opposite direction; (ii.) *The earth itself is one of the planets, all of which travel round the sun in the same direction*, as shown in figure 5, where, with the sun in the centre, Venus and Mercury are assigned orbits within that of the earth, and the outer planets orbits beyond that of the earth, each planet travelling the more slowly as it is farther from the sun. Thus the earth is removed by Copernik from the centre of the universe, and placed among the planets which seem to travel round it, and the sun, regarded as being at rest, takes the place which had hitherto been assigned to the earth. A consideration of Fig. 6, which represents the relative orbits of the earth and Mars, will serve to make clear how the main features of the apparent movements of an outer planet were explained according to the Copernican theory. The inner circle represents the track of the earth in its uniform motion round the sun S situated in the centre of the circle; this circle is divided into 12 equal divisions (marked by Roman figures), representing the 12 equal portions of the track supposed to be passed over in the 12 months of the year; the outer circle represents the track (or orbit) of

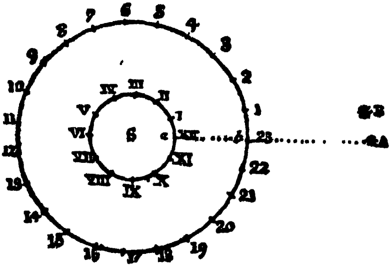

Fig. 6.

the planet Mars, which takes 687 days, or, roughly, 23 months, to go round the sun; and the 23 equal divisions of this circle (representing the 23 equal portions of the track passed over in the 23 months of the planet's year), are marked with Arabic numerals. Now let us suppose the earth to be at XII., and Mars at 12 on the opposite side of the earth to the sun (when he is said to be in *opposition*), then it is clear that Mars will be seen from the earth in the direction a b produced far away among the stars. Now, since the earth, in travelling along her orbit, reaches the positions I. and II. on the inner circle in the same time that Mars reaches the points 1 and 2 on his outer circular track, it is evident that he will be left behind by the earth in her more rapid progress, and thus will appear to be travelling backwards or *retrograding;* when the earth reaches IV. and Mars 4 (at the end of the fourth month), it will be seen that the earth is moving directly from Mars, so that his only apparent motion will be that due to his actual forward movement towards 5, and he will therefore seem to be advancing. At some intermediate point where his retrograde motion changes into a forward motion, Mars will appear to be stationary. At the end of the twelfth month, when the earth has come to the point whence she started, Mars will be at 12 on the opposite side of the sun; as the earth moves from XII. to I. the outer planet moves from 12 to 13, and since the two are thus moving in opposite directions Mars will, during this portion of his course, appear to be advancing most rapidly. By the time that Mars has reached 22, the earth will have got round to X. again, and will be moving directly towards the outer planet, which therefore will seem to be advancing with its own motion only. When the earth again reaches I. (at the end of 25 months), Mars will be once more in opposition at 2, and in the middle of his retrograde course. It will be observed, moreover, that when Mars is in opposition (in the middle of the retrograde arc) he is nearest to the earth, and therefore appears brighter than when in any other position, and this is always actually observed to be the case. It must be noted, however, that although the larger characteristics of the planetary motions were thus explained by Copernik, the minute irregularities were still accounted for by a system of epicycles.

It was not until nearly a century after Copernik's time that the great verifications of his theory were made, and, in the meantime, while many astronomers accepted his theory, others rejected it, or held a modification of it. There were, in fact, many difficulties in the Copernican system which prevented its general acceptance. In the first place, the fact that the angular distance between two fixed stars appeared to be the same throughout the year showed that if Copernik's theory of the earth's annual revolution round the sun were correct, the fixed stars must be at an enormous distance from the earth as compared with the distances of the planets, for it is clear that the angular distances of two stars (A and B in Fig. 6), as observed from the earth when at VI., and when at XII., would not be the same unless A and B were at practically infinite distance. Telescopic observation shows that the stars actually are at such great distances, but in Copernik's time there was nothing to lead people to think so.

Again, it had long ago been recognised that the *phases* of the moon were due to the fact that it shines by the light reflected from the sun, which can, of course, illuminate only one-half of its surface at a time, while the amount of the illuminated surface which can be seen from the earth will evidently vary with the changing position of the moon in the sky. When, for example, the moon is on the same side of the earth as the sun, its dark side is turned towards us, and we cannot see it at all, unless (as happens at least twice a year) it comes just between the earth and the sun, causing an eclipse of the sun; a little later it appears as a thin crescent, nearly all the dark side being turned towards the earth; at about a week after the time of new moon, it having got ¼ round in its orbit, we find the moon high up above our heads when the sun is just setting in the west, and we see about half the bright side; a week later we find the moon rising in the east as the sun sets in the west, and being thus right opposite the sun it appears as full, and we see the whole illuminated half of its surface. (If when sun and moon are both above the horizon a spherical body be held at some distance from the observer in the direction in which the moon is observed to be, it will be found that the portion of the body which is seen to be illuminated by the sun has exactly the same shape as the moon at the same time.) Now, if Copernik's theory were true it was seen that Venus and Mercury should also show phases like the moon, but such had not been observed. It was thought, too, that if the earth were really moving, its inhabitants would be conscious of the fact; moreover, it appeared that a stone dropped from the top of a tower ought to fall towards the west if the earth were moving rapidly away under it to the east, but this was not observed to be actually the case. Further, it was found that as more exact observations were made, the positions of the various planets for any given time calculated in accordance with the motions assigned to them by Copernik did not *perfectly* agree with their positions as actually observed.

Seeing these difficulties of the Copernican theory, Tycho

Brahe (the most careful observer of his time) suggested a modification of it; he supposed the earth to be at rest, while the celestial globe revolves round it once a day, the planets having, besides, independent movements round the sun, just like those assigned to them by Copernik.

5. **Kepler's Laws.**—Tycho Brahe's pupil, Johannes Kepler (born 1571, died 1630), who succeeded him, in 1601, as Imperial Mathematician to the Emperor Rudolph II. of Bohemia, made use of his observations—especially a series of observations on the planet Mars—in order to try so to modify the Copernican theory as to make a better agreement between the theory and the observed facts. At first he adopted Copernik's idea of uniform motion in a circle, with the sun at the centre, and he tried many combinations of various circular motions without much success. He then supposed the sun to be placed not exactly at the centre of the circle representing each planet's orbit, and found that this supposition accorded more nearly with Tycho's observations. Still the agreement was not perfect, and at length it occurred to Kepler that the notion of *uniform* motion in a circle might be wrong, and that the observed greater rate of the sun's apparent motion in the heavens at different parts of the year might be due to a real variation in the earth's motion round the sun. After trying several theories of varying motion, he at last found one which exactly agreed with the observations of Tycho Brahe. According to this theory, the orbits of the earth and the other planets are supposed to be *ellipses*, instead of circles. (An ellipse is the curve which is traced out by a point which moves in such a way that the sum of its distances from two fixed points—*ff'* Fig. 7—remains constant. These two fixed points are termed the *foci* of the ellipse, and the diameter

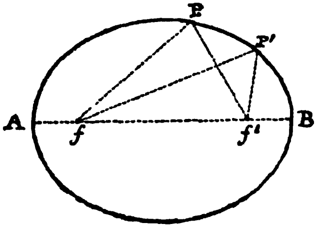

Fig. 7.

A B drawn through them is the *major axis*. A simple method of drawing an ellipse consists in passing a loop of string over two pins placed as at ff', and moving a pencil point put in the loop so as to keep the string stretched to its full length, as shown at P P'.) Moreover, the motion of a planet in its elliptic orbit, instead of being uniform, was supposed by Kepler to vary in such a way that the line joining the centre of the planet to the centre of the sun (called the planet's *radius vector*) passes over *equal areas in equal times*; thus in Fig. 8, representing in an exaggerated form the earth's path round the sun S, the earth is at its greatest distance from the sun at a, and it travels from a to b in the same time (one month) as it travels from b to c, c to d, and so on. It will easily be seen that the distances e to f, f to g, for instance, are greater than the distances a to b, b to c, but the areas of the triangles Sab, Sbc, Sef. Sfg, and so on, are all equal. In 1609, Kepler published his "Commentaries on the Motion of Mars," containing these theories, which may be shortly enunciated thus :—

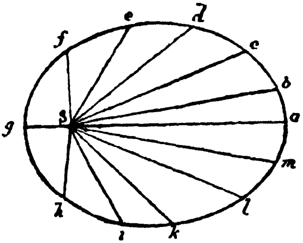

Fig. 8.

(i.) *The planets move in ellipses, with the sun in a focus of each* (**Kepler's first law**).

(ii.) *The radius vector of each planet sweeps out equal areas in equal times* (**Kepler's second law**), At about this time the invention of the TELESCOPE afforded new evidence of the truth of the main points of the Copernican theory. Galileo, whilst Professor of Mathematics at Padua, heard of this invention (due to a Dutch optician), and soon succeeded in constructing such a telescope for himself. He found, on looking through the telescope, that while the fixed stars remained mere *points* of light, the planets were magnified into luminous *discs*, thus confirming the view that the stars were at immensely greater distances, as required by the Copernican theory. Then he observed that Venus actually did exhibit *phases* like the moon, thus clearly proving that she revolved round the sun. In the beginning of the year 1610, Galileo discovered four moons revolving round the planet Jupiter. Here, then, was a sort of Copernican system in miniature, which served better than many arguments to convince people of the truth of the theory. Other telescopic observations of Galileo's, which likewise served to promote the more general acceptance of the true theory of the planetary motions, were the discovery of mountains and valleys on the surface of the moon, which had always been regarded as perfectly smooth; and of *spots* on the sun's surface, by means of which it was proved that the sun rotated on an axis. This proof of the rotation of the sun made it much more easy for people to believe that the earth also might have a similar movement.

It was not, however, until more than two hundred years after the time of Kepler and Galileo that an *experimental proof* of the earth's daily rotation on its own axis was given by Foucault's celebrated PENDULUM EXPERIMENT in the Pantheon at Paris in the year 1851. A heavy metal globe was suspended over the centre of a round table by a long thin wire attached to the roof of the dome of the Pantheon, and was then made to swing as a pendulum by drawing it to one side, without giving it any movement of rotation round the vertical. Now, it can be proved that a pendulum thus set swinging cannot, if left to itself, change the plane in which its oscillations are performed, and thus, if the table remains unmoved, the line N S, marking the intersection of the plane of vibration with the plane of the table, should remain unaltered as long as the pendulum continues to swing. But Foucault found that the direction of swing appeared to change, so that supposing the pendulum to have been started swinging in the plane of the meridian N S, it was found after a time to have apparently deviated into the positions N_1 S_1, N_2 S_2, etc. Since the plane of oscillation really remains unaltered, this apparent change must be due to an actual revolution of the table, in the direction N S_2 S, caused by its being carried round with the earth in its daily rotation. From the apparent rate of rotation of the plane of vibration of the pendulum, the time of the earth's rotation can be determined without reference to astronomical observations. Foucault subsequently used a GYROSCOPE (which may be regarded as a heavy top supported at both ends of its axis) as a means of proving the earth's rotation. The axis of such a rapidly rotating body will, unless extraneous force be applied, remain unchanged in direction, so that if it points towards a certain star, it will continue to point to that star as long as the rotation continues, if the star remains in the same place—*i.e.*, if the apparent motion of the star be due to a real motion

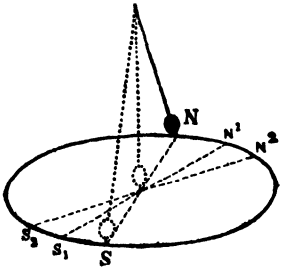

Fig. 9.

of the earth in the opposite direction. Foucault found that this was actually the case.

A most convincing physical proof of the earth's annual *revolution* round the sun had been obtained in the previous century from Bradley's discovery of the **aberration of light** in 1727. Bradley, whilst trying to find the *parallax (see* page 38) of a certain star, found that it appeared to describe annually a small ellipse in the sky. It was soon found that the other fixed stars also described such ellipses, which became nearly circles in the case of stars furthest away from the ecliptic, and straight lines in the case of stars on the ecliptic—the major axis of the ellipse always being constant. Now, it had been already shown by Römer, in 1675, from observations on the eclipses of Jupiter's satellites, that light travels at the rate of about 186,000 miles per second. He noticed that when the earth was furthest away from Jupiter, as at E_2 (Fig. 10), there was a retardation in the time of the eclipse of the first of Jupiter's satellites equal to 16 minutes 36 seconds, and he argued that this must be due to the fact that a ray of light, instead of travelling instantaneously, takes this time to cross the distance from E_1 to E_2, or the diameter of the earth's orbit. The value thus obtained has since been confirmed by purely experimental methods. Now, Bradley saw that if the earth is really travelling round the sun with a velocity at all comparable to that of light, the light travelling from a star to the earth may be compared with the case of rain falling perpendicularly on to a body

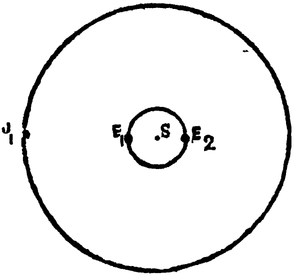

Fig 10.

moving in a horizontal direction. A drop of rain falling from the point R (Fig. 11) will pass right through a perpendicular tube A B so long as the tube remains at rest; if, however, it be carried forward with a velocity comparable to that of the falling raindrop, the drop will strike the side of the tube, and thus fail to pass through. In order that the drop may pass right through the moving tube, this must be tilted in the direction of motion into some such position as B C, the amount of inclination depending upon the velocity with which the tube is being carried forward. If, for example, a drop falls through the distance C D in the time that the tube moves from B to D, it follows from the parallelogram of velocities that the tube must be placed in the position B C. Now, we may consider the tube as a telescope required to receive the rays of light from a particular star, S. If, while the light is moving from C to D, the earth moves onward (carrying the telescope with it) from the position B C into the position D E, the light will evidently reach the eye-piece at D; the telescope must then be directed, not straight to the star, but slightly tilted in the direction in which the earth is moving in its orbit, hence the observer will see the star at S¹ in the direction D E, in which the telescope is pointed, so as to make a small angle (about 20″) with the true direction of the star. As this direction changes with the changes in the direction of the earth's motion as it travels in its slightly elliptical orbit, it is evident that during the course of the year a star

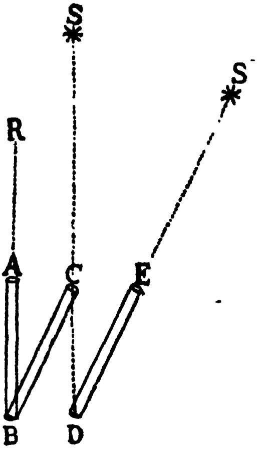

Fig. 11.

near the pole of the ecliptic will seem to describe a similar ellipse of very minute size, the eccentricity of this aberration ellipse will increase owing to foreshortening in the case of stars farther away from the pole until it becomes a straight line for a star placed in the ecliptic. Thus, in Fig. 12, if A C B D represents in perspective the earth's orbit, a star S, whose true direction, as seen from the points A and B on this orbit, is shown by the dotted lines A S B S (for the star being at a practically infinite distance, its direction, as seen from all points on A C B D will be the same), will appear from A in the direction in which the telescope is slanted A a, but when the earth is on the opposite side of its orbit, at B, the telescope must evidently be pointed in the opposite direction B b, and the star will appear to be displaced accordingly. If the star is on the ecliptic at S^1, the lines C c and D d show the directions in which the telescope must be pointed in order that the star may be seen from C and D respectively. In this case there will evidently be no displacement when the earth is at A or B, and moving directly towards or from the star. In the diagram the amount of displacement is of course greatly exaggerated, the real value of the angles S B b, S^1 D d, etc., being about a third of a minute.

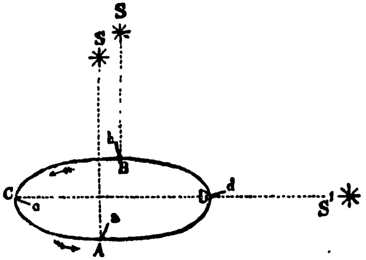

Fig 12.

Knowing this angle, *i.e.*, the amount of the observed displacement of a star, and the velocity of the earth in its orbit (which is about 19 miles per second), it is easy to calculate what must be the velocity of light. Bradley showed that the value thus obtained agreed with that found by Römer. This agreement served to confirm the truth of his explanation of the phenomenon of aberration, which is seen to give an independent proof of the annual revolution of the earth round the sun, as required by the Copernican theory.

In 1619 Kepler published his "Harmonies of the World" (dedicated to James I. of England), containing the celebrated law that "*The squares of the periodic times of the different planets are proportional to the cubes of their mean distances from the sun*" **(Kepler's third law)**; that is to say, that the mean distance of a planet (defined as being half the major axis of the ellipse representing the planet's orbit) is always related to its periodic time T (defined as the planet's year, or the time it takes to describe its orbit) in such a way that $\frac{d^3}{T^2}$ is a constant. In the following table the mean distances and periodic times of Venus and Mars are given in terms of the mean distance and periodic time respectively of the earth considered as unity :—

	Earth.	Venus.	Mars.
d . . .	1	0·723	1·524
T . . .	1	0·615	1·881
d^3 . . .	1	0·378	3 537
T^2 . . .	1	0·378	3·537

It will be observed that in each case d^3 (*i.e.*, d × d × d) is equal to T^2 *i.e.*, T × T).

References.—Stuart's *A Chapter of Science* (S.P.C.K.).
Morton's *Astronomers* (Heroes of Science Series. S.P.C.K.).
Lodge's *Pioneers of Science* (Macmillan).

Section II.—Universal Gravitation.

1. **The Laws of Motion.**—By the discoveries of Copernik and of Kepler the old theory of Epicycles had been finally disproved, but the great problem still remained. How was it possible to *account for* the motions of the planets? Various speculations had indeed been made. Kepler had suggested the idea of *spokes* issuing from the sun and pushing the planets round in their orbits; Descartes (born 1590, died 1650) held a theory of *vortices* or whirlpools of air or "ether" which carried the planets along with them, but it was reserved for the genius of Isaac Newton (born at Woolsthorpe, Lincolnshire, 1642, died 1727) to discover the true law. Galileo had already investigated the laws of motion, and had shown that the natural free state of motion of a body is uniform motion in a straight line, and not motion at a uniform rate in a circle as the ancients had thought; for he observed that in all cases when a body does pursue a circular path, as for example a whirling stone attached to a string, or a whirl of liquid in a circular vessel, there is some force tending to *deflect* the body into its circular track; and if this force ceases to act, as when the string breaks, the body moves off at a tangent to the circle, as shown in Fig. 13 where A represents the hand at the end of the string; B the stone; and B C the direction in which it will move from the point B, if the string be loosed or cut. Moreover, it appeared that a body would naturally go on moving in a straight line for ever were it not for friction or some other resistance tending to stop its motion; for the more we diminish this resistance, the longer will a body move; a stone on smooth

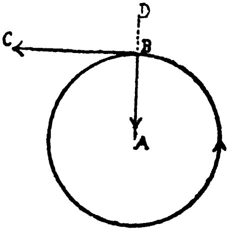

Fig. 13.

ice, for instance, will go much farther than if projected along a rough road. Newton afterwards stated his **first law of motion** as follows :—*Every body continues in its state of rest or of uniform motion in a straight line, except in so far as it may be compelled by force to change that state.* It will be seen that the law as thus stated gives us a definition of **force,** which is anything which changes a body's state of rest or of uniform motion in a straight line. The fact that a body if at rest will remain at rest, and if in motion will remain in motion, apart from the action of external forces, is shortly expressed by the statement that Matter has *Inertia.* The first law of motion tells us what force is, but gives no means of measuring it : this we learn from the **second law of motion** discovered by Galileo and stated by Newton in the following terms :—*Change of motion is proportional to the impressed force, and takes place in the direction of the straight line in which the force acts.* It is a matter of common experience that the force or effort required to move a body when at rest or to stop it when in motion, depends upon its mass as well as upon its velocity, that, for example, it is easier to stop a small pebble rolling down a slope than a large boulder. The *quantity of motion* of a body, or the product of the number of units of its mass into the number of units of its velocity is termed its **momentum**; the unit of momentum being that of a unit of mass moving with a unit of velocity. The phrase "change of motion" in Newton's second law of motion is intended to mean "rate of change of momentum," and the law shows that when we are dealing with a single body whose mass remains constant, a force is to be measured by the rate at which it produces change of velocity (or acceleration); a *unit of force* is that which produces in a unit of mass a *unit* of acceleration. In the C. G. S. system the unit of force is that force which generates per second in a mass of one gramme a velocity of one centimetre per second. A force is said to be constant if it produces equal accelerations in equal times. Such a constant force is that of terrestrial *gravity*, the nature of whose action was investigated by Galileo. He found, by means of experiments with bodies sliding down inclined planes, that the spaces passed over by a body (starting from rest) under the action of a constant force are proportional to the squares of the times; in the case of a stone dropped from the top of a cliff, for example, it is found that in one second it falls, roughly speaking, 16 feet; in two seconds 64 feet, in three seconds 144 feet, and so on. In this case, at the end of one second, the stone has acquired a velocity of 32 feet per second, so that it would, if not acted upon by any force, continue to move with this velocity, but the force of gravity is continually adding on velocity, and during the second second the stone has thus added to its motion a velocity of 32 feet per second, so that at the end of this second it will be moving with a velocity of 64 feet per second; at the end of the third second, with a velocity of 96 feet per second, and so on, the velocity at the end of t seconds being represented by $t \times 32$, while the space traversed in t seconds is represented by $t^2 16$.

Galileo further showed by experiments on bodies falling from the top of the leaning tower of Pisa, that all bodies (except for the resistance of the air) fall at the same rate. It had been asserted by Aristotle that a 10 lb. weight would fall to the ground ten times as quickly as a 1 lb. weight, and at first sight this seems a reasonable proposition, for the force of gravity or the pull of the earth upon the larger weight is ten times as great as it is upon the smaller. A further consideration, however, shows that, since in the 10 lb. weight, there is ten times the matter to be moved, *i.e.*, since it has ten times the mass of the 1 lb. weight, it will require a force ten times as great to move it with the same velocity. The second law of motion may be expressed in another form, thus: *If any number of forces act on a body, each force produces its own change of momentum quite independently of the action of any other force.* Galileo was led to recognise this truth by considering the motion of projectiles; if a cannon-ball be fired in a horizontal direction at a great height above the ground, it is found that it falls just as quickly and reaches the ground (if flat) in exactly the same time as if it had been merely dropped from the same height. The vertical velocity due to the action of gravity is thus quite independent of the horizontal velocity due to the force of projection, and the same is true in every case, *viz.*, that, however many forces may be acting on a body either at rest or in motion, each has the same effect in producing change of motion as if it were the only force acting. The important geometrical propositions known as the PARALLELOGRAM OF VELOCITIES and the PARALLELOGRAM OF FORCES follow from this. Suppose a body placed at A (Fig. 14) to have imparted to it simultaneously two velocities, one of which would carry it from A to B in a second, and the other from A to C, then the lines A B and A C may be regarded as representing these velocities both in magnitude and direction. Now, if the velocities were communicated successively the body would move from A to B and from B to D, where B D is drawn parallel and equal to A C. Hence, the *resultant* of the two velocities, or the single velocity which is produced as the result of their concurrence, will be

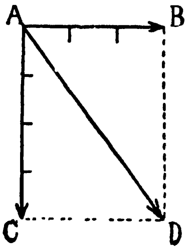

Fig. 14.

represented in magnitude and direction by the diagonal A D of the parallelogram A C D B.

Now, since a force is completely specified when its point of application, its direction, and its magnitude are known, it follows that forces can, like velocities, be represented by straight lines. Thus the line A B may be taken to represent a force whose point of application is A, whose direction is A B, and whose magnitude is given by the number of units of length in A B on any suitable scale. Hence the same construction which serves to determine the resultant of two simultaneously communicated velocities may also be used to find the resultant of two forces acting on a body at the same time, or "if two forces represented in magnitude and direction by two straight lines meeting at a point, act upon a body, they will together be equivalent to a single force represented by the diagonal passing through the point, at which the straight lines meet, of the parallelogram of which they are adjacent sides."

Newton's **third law of motion** is, "*To every action there is an equal and contrary re-action; or the mutual actions of any two bodies are always equal and oppositely directed.*"

In this law, Newton points out that force is always *dual*, that whatever change of momentum is produced in a body by any pull, push, or pressure, exerted by another body, precisely as much will be communicated to this body in an opposite direction.

The action and re-action taken together constitute what is termed a **stress**, and the forces may be regarded as aspects of this stress. We have familiar instances of the application of this law in the recoil of a gun, and in the ascent of a rocket caused by the downrush of heated gases escaping from its lower end. Again, when (as will be considered in the next section) the earth attracts the moon and keeps it in its orbit, the moon also attracts the earth, this attraction being the chief cause of the phenomena of the tides. In a second interpretation of this law given by Newton, there is contained (as was first pointed out by Lord Kelvin and Professor Tait) almost the whole of the modern doctrine of energy (ch. iv.).

2. **The Law of Gravitation.**—We will now consider how a knowledge of the laws of motion enabled Newton to give a DYNAMICAL interpretation of the KINEMATICAL laws of planetary motion discovered by Kepler. It will be evident, in the first place, that the force required to account for a body moving in a nearly circular path is not, according to the first law of motion, one to *keep up* motion, as Kepler had thought, but one to *alter* it from a straight line into an elliptic or circular orbit. Thus in Fig. 16, a body at B would naturally, when once started, move on uniformly in the direction B C for ever, if not acted upon by some force; in order to deflect it into the circular path B D, it must be pulled towards A, the centre of its orbit, by some continually acting force. Now, in the case of the planets it had already been suggested that since the sun is inside the orbit of each planet, the force required might be one acting towards its centre. A pupil of Galileo's, named Borelli, had, indeed, compared the case of the sun and a planet with that of a stone whirled at the end of a string. Newton's first idea of the law of gravitation was suggested by a considera-

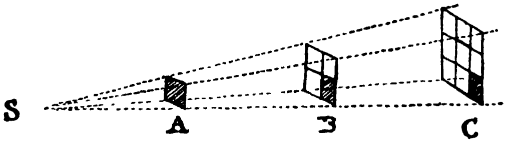

Fig. 15.

tion of the moon's motion. Could "gravity," he thought, the well-known force which gives to terrestrial bodies their property of weight, and causes them to fall to the ground, also be the force which bends the moon's path into her nearly circular orbit? It appears to have already occurred to several observers, that the force which pulls the planets towards the sun might decrease according to the square of the distance, *i.e*, at twice the distance be a quarter as great, at three times the distance one-ninth as great, and so on. [This law was suggested by the analogy of light, it being known that if the light from a luminous body falls upon a surface, the quantity of light which the surface receives varies in this manner, as may be seen by an inspection of Fig. 15. The light from the luminous point S is supposed to fall upon a square disc A placed at unit distance, and it is evident from the figure that if A be removed, the same amount of light would fall upon the disc B, *four* times as great, placed at *twice* the distance from S. Hence the light which falls upon a portion of B, equal in size to A, will be one-fourth of the amount which falls upon A, that is, the amount of light received will vary as the square of the distance from the luminous source.]

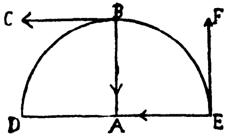

Fig. 16.

Newton then calculated what would be the force of gravity at the distance of the moon from the earth if it continued so far, on the supposition that it decreased according to the law of inverse squares. Owing, however, to a mistaken estimate of the moon's distance from the earth, the result of the calculations did not agree with the result of direct observation on the form of the moon's orbit, and he abandoned the idea for a time. This was in 1665, when Newton was 23 years old.

It will be useful to consider here without entering into details (which will be found in any astronomical treatise) the way in which the MOON'S DISTANCE can be determined. For this purpose we require to find the moon's **parallax**, that is the angle between its direction as seen from two different places on the earth's surface. If simultaneously observed for example from two observatories, A and B situated on the same meridian, the moon will evidently not appear at both places in the same position among the stars, but will be seen from A in the direction A S_1 (farther to the south) and from B in the direction B S_2. The angle A M B is the parallax corresponding to the arc of meridian A B between the two observatories. From the value of this angle the moon's horizontal parallax, or the angle subtended by the earth's radius as seen from the moon, may be determined. This angle is found to be approximately $57' 2''$ whence by trigonometry it may be proved that the moon's distance is, roughly speaking, 60 times the length of the earth's radius, or 240,000 miles.

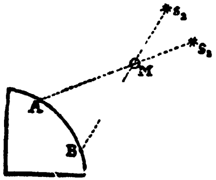

Fig. 17.

In 1679 Picard made a new measurement of the earth's radius, and three years afterwards Newton heard at the Royal Society of Picard's result, which differed considerably from the value assumed by Newton in his earlier calculations. With a more correct estimate of the moon's distance, Newton returned to the theory which he had suggested in 1665, and succeeded in showing the complete accord of the theory with the observed rate of movement of the moon. We have seen that the attraction of the earth on a body at its surface causes it to fall through a distance of rather more than 16 feet from rest in one second, therefore if Newton's idea of the law of Gravitation were correct, it followed that at the distance of the moon (60 times farther off from the earth's centre) the pull of the earth's attraction would be just able to cause a body to fall through $\frac{16}{(60)^2}$ or $\frac{16}{3600}$ foot or $\frac{1}{225}$ foot in one second; (for by the second law of motion, the moon falls towards the earth just as much each second as if it had no orbital velocity); in other words, the distance through which a falling body is drawn in a second at the earth's surface would be 3600 times as great as that through which a falling body would be drawn at the distance of the moon. Now, it is of course easy to calculate from the size of the moon's orbit and the time taken to describe it what the deflection of the moon's path from a straight line in any given time actually is, and Newton found that the moon was thus pulled towards the earth by just $\frac{16}{3600}$ foot in a second, thus showing that the force exerted by the earth upon the moon is really the same force. During the two next years Newton worked out completely the great theory of gravitation, showing that it follows from Kepler's first law that each planet is held in its orbit by a force directed to the sun's centre; from his third law, that it is the same force for all the planets, and from the first and third laws, that the force varies in each case inversely as the square of the planet's distance from the sun; the same force, moreover, acts between the planets themselves, each planet being attracted by all the other planets as well as by the sun, and hence *perturbations* are introduced into the form of their orbits, which are found to be not quite in accordance with Kepler's laws. These perturbations, or disturbances of what would otherwise be the simple elliptic motions of the heavenly bodies are especially marked in the case of the moon.

Certain of these irregularities are due to the oblateness of the earth's figure, whereby the moon is pulled not quite to the earth's centre. Such phenomena as this show that it is not only the centres of the different bodies which attract one another, but that every particle attracts every other particle.

In 1687 Newton produced his great work, the "Philosophiæ Naturalis Principia Mathematica," commonly known as the "Principia," in which all these facts are summed up in the statement that "every particle of matter in the universe attracts every other particle with a force varying directly as the product of their masses, and inversely as the square of the distance between them." It is sometimes popularly stated that Newton discovered "Gravity," and "explained why bodies fell to the ground." This is quite an erroneous view of Newton's great work. The idea of gravity as some force attracting bodies towards the earth's surface was not a new one, and Galileo had already, as we have seen, partially investigated its action; but no one had suggested that this same force of gravity kept the earth and the other planets in their orbits, still less that every particle in the universe possessed this wonderful power of attracting every other particle in the way stated by Newton in his law of universal gravitation. The real *cause* of gravitation is not touched upon in the "Principia." Since Newton's time several theories have been advanced to account for the phenomena of gravitation, but none of them can be regarded as being more than suggestive speculations. It has already been mentioned that a body weighs less at the equator than it does nearer the poles. It will be seen that this follows from the law of gravitation, and the non-sphericity of the earth, for a body at the poles being nearer to the centre of the earth, the pull of gravity will be stronger there. It can be shown that gravity should be $\frac{1}{289}$th less at the equator than at the poles, if we merely take into account the effect produced by the shape of the earth, but it is actually $\frac{1}{193}$ less. The difference ($\frac{1}{399}$) is due to the tendency of a body at the equator to fly outwards along the straight line in which it is moving at any given time. (This tendency is often conveniently, though not very accurately, spoken of as *centrifugal force*). It constitutes an additional argument for the rotation of the earth, for the difference is exactly what calculation shows should be the case if the earth be rotating on its axis once every 24 hours. The shape of the earth itself Newton explained as being due to the same centrifugal tendency. Newton also showed how from the laws of motion a very strong argument in favour of the earth's rotation can be deduced from the motion of falling bodies; for since a body at a considerable height above the earth's surface has a greater eastward velocity (since it moves in a larger circle) than a body on the surface, it ought to fall somewhat to the east of the vertical. The experiments made in Newton's time were not conclusive, the amount of fall being too small to give a measurable deviation. Among subsequent experiments, those of Prof. Reich in the mines of Freiberg, are perhaps the most striking. As the result of 106 experiments in which balls were dropped through a distance of 488 feet, there was a mean deviation of 0·46 lines to the south, and 10·32 lines to the east.

One of the most striking proofs of the theory of gravitation is that furnished by the discovery of the planet Neptune. In 1781 Sir W. Herschell discovered the planet Urănus. After its motion had been carefully studied, an orbit was assigned to it, and for some time its observed motion agreed very well with the theory; then for several years it was found to be in advance of its calculated position, and afterwards it began to fall behind. It had been suggested that these irregularities might be accounted for by the perturbing influence of an unknown planet outside Uranus, and in 1846, Leverrier (in France) and Adams (at Cambridge) independently worked out the very difficult problem of assigning the approximate mass and position of an exterior planet which would produce the observed irregularities. The results obtained (by different methods) were very nearly the same, and on the 24th of September in the same year the new planet was first recognised by Dr. Galle of Berlin, within a degree or so of the place assigned to it.

3. **The Weight of the Earth.**—In order to weigh the earth all that we have to do is to compare the attraction of a large heavy ball (say of lead) upon a small suspended body, with the weight of the body, that is with the attraction of the earth upon it. The experiment was first made by Cavendish, who used a "torsion balance" to measure the attraction of the lead balls. By making use of the fine elastic fibres of quartz obtained by Professor Vernon Boys (p. 68), it is possible to measure the force of attraction between bodies as small as ordinary bullets.

From his experiments, Cavendish concluded that the earth is about 5½ times heavier than if it were a globe of water. This result has been confirmed by other methods.

References.—Works cited on page 30, and (for laws of motion) Maxwell's *Matter and Motion.*

Section III.—Consequences of the Earth's Rotation and Revolution.

1. **The Seasons.**—It will be convenient to briefly consider here how the earth's daily rotation on its axis and its annual revolution round the sun, cause the phenomena of day and

night, and of the changes of the seasons. It can be shown that the momentum of the earth's rotation is sufficient to render the position of its axis constant (just as in the case of a gyroscope), so that it always moves parallel to itself, making an angle of 66° 33′ with the ecliptic or plane of the earth's orbit, and points in the same direction to the heavens: (this statement is not strictly accurate). Now, as the earth rotates on its axis, one half of it is always exposed to sunlight, the other remaining in darkness, but as the hemisphere of light or darkness lies obliquely to the axis (Fig. 18), it will be seen that the length of day and night will vary at different parts of the earth's surface at different times of the year. When the earth is at E (at the summer solstice of the northern hemisphere) the north pole is inclined to the sun and all the region within the *Arctic circle* (23½° from the pole) remains in daylight during the whole period of rotation. Similarly the South Pole is inclined away from the sun, and the space within the *Antarctic circle* remains in continual darkness. In this position the middle of the illuminated hemisphere is 23½° N. of the equator (on the tropic of Cancer), the highest north latitude at which the sun is vertical. The term *solstice* (standing of the sun) indicates that at this time the sun, having reached its greatest distance north of the equator, appears to stand

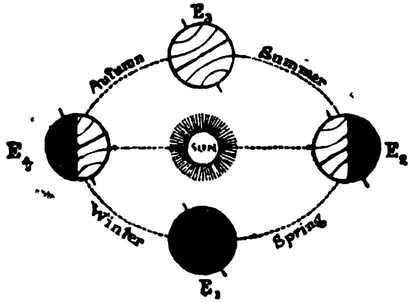

Fig. 18.

still before its motion is changed in direction towards the equator again. When the earth is in the positions E and E_3 neither pole of the earth's axis is inclined towards the sun, which will be vertically over the equator, and will seem to describe the circle of the equator in the heavens; the illuminated hemisphere will then extend from pole to pole, and during the rotation of the earth, all points on its surface will have 12 hours' sunlight and 12 hours' darkness. Then day and night are equal all over the earth. Hence the term equinox, used to indicate these times (21st March, 22nd September). At the *winter solstice* when the earth is in the position E_4 the south pole will be turned towards the sun, which will be vertical over the tropic of Capricorn (so called because the sun then enters the constellation of that name). Since the tropics include between them all those points on the earth's surface at which the sun is ever vertical, and where, therefore, his maximum heating power is felt, the region of the earth's surface thus marked out is known as the TORRID ZONE. Within this zone the variation in the obliquity of the sun's rays is never great enough to cause very much difference in its heating effects. At places within the north TEMPERATE ZONE (between the tropic and the arctic circle) the sun's rays fall much more obliquely when the earth is at E_4 than when it is at E_2; in other words, at the winter solstice, the same amount of solar radiation will fall upon a much larger space; moreover, it will have to pass through a greater depth of atmosphere, which absorbs some of the heat. This is the chief cause of the greater heat of summer and cold of winter, another being the greater length of day in summer, whereby the earth receives heat for a longer time. As, however, during the summer more heat is received in the day than is lost by radiation into space at night, the supply goes on accumulating, as it were, and thus the greatest heat of summer occurs nearly a month after the summer solstice. It will be seen from the diagram that winter in the northern hemisphere and summer in the southern hemisphere occur in perihelion (when the earth is nearest to the sun). Since, however, according to Kepler's second law, the earth moves more rapidly when near the sun, the greater heat of the southern summer is compensated for by its shorter duration.

2. **Deflection of Bodies moving on the Earth's Surface.**—Since any place situated on the equator is moving with an eastward velocity of over 1,000 miles an hour, while places situated in latitude 60° are moving at only half this rate (just as in a wheel a point on the outer rim moves faster than the hub), it will be seen that if a body, say a cannon ball, were to be projected from the equator towards the North Pole, it would, in virtue of its greater eastward velocity (according to the first law of motion), be moving relatively to the earth in a N. E. instead of a N. direction, while, on the other hand, a body projected from the North Pole towards the equator, and thus continually reaching places having a greater eastward velocity, would move in a S. W. instead of a S. direction. In each case the deflection would be to the right hand. Similarly bodies moving in any direction in the southern hemisphere are deflected by the earth's rotation towards the left hand. The effects of this deflection are actually observed in the case of winds and ocean currents (pp. 110 and 128).

3. **The Tides.**—Newton was the first to show how the rhythmic rise and fall of the oceanic waters, known as the TIDES, is due to the combined action of the earth's rotation, and the greater attraction of the moon (and sun) upon the nearer than upon the more remote parts of the earth. The effect of this unequal attraction upon the solid lithosphere is not marked, but the liquid hydrosphere is caused to

assume a more spheroidal form, the water being heaped up on opposite sides of the earth. Owing to the earth's rotation the two *crests* with their intervening *troughs* thus produced are not stationary, but tend to follow the moon, so that high water and low water occur (speaking generally) twice every lunar day of 24 hours, 54 minutes; the interval between high and low tide being thus about 6¼ hours at any one place. Owing to the irregular configuration of the land and sea the actual movements of the oceanic waters are extremely complex, and cannot be explained without mathematical reasoning. The tidal action of the *sun* is less than that of the moon in the proportion of about 2 to 5, because, although his mass is enormously greater, he is so much farther away from the earth.[1] At new and at full moon the solar and the lunar tides act conjointly, and we get *spring* tides. At half moon they act in opposition and we have the lower *neap* tides.[2]

Similar tides are produced in the atmosphere, but the air is so much affected by other causes that they are hardly perceptible.

The influence of tidal action in the evolution of worlds will be noticed in Chapter VI.

References.—Proctor, *The Seasons Pictured* (Longman). And for *Tides*, Lord Grimthorpe's *Astronomy without Mathematics* (S.P.C.K.). And *The Tides*, by T. K. Abbott (Longman).

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[1] The attraction of the sun upon the earth as a whole is 200 times greater than that of the moon, but the *difference* between the attracting force upon the nearer and more remote sides of the earth is less in the case of the sun than in that of the moon, and it is this *differential* attraction which causes the tides.

[2] *Neap*—scanty or nipped; *spring*—uprising or upspringing.

CHAPTER III.

THE MATERIALS OF THE EARTH.

Section I.—Matter and its Forms.

1. **Chemical and Physical Changes.**—That we are surrounded on all hands by a number of different substances, each possessing its own distinctive properties, is a fact familiar to everyone. Iron evidently differs in many respects from wood, and water from alcohol and mercury. That these and many other substances are liable to constant change is also a matter of common observation. The iron rusts if left exposed to the air; the wood if sufficiently heated in the air burns away, and for the most part disappears; the water if heated boils, and in cold weather freezes into solid ice. Some of these changes we call *chemical* changes, the others we call *physical* changes. In chemical changes, *change of properties is always accompanied by change of composition.* The conversion of ice into water, or of water into steam, is merely a *temporary* change of *state.* The steam when cooled condenses again into the liquid water, which, when further cooled, passes back into the solid ice. When, however, a current of electricity is passed through water (rendered slightly acid by the addition of a few drops of sulphuric acid) a *more permanent* change of *composition* re-

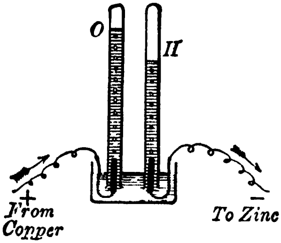

Fig. 19.

sults; bubbles of gas (Fig. 19) are seen to rise through the water from the platinum wires or plates connected with the battery, and when collected and examined, it is found that two distinct kinds of gas have been produced; one of them, that produced at the negative electrode (wire coming from zinc plates of battery) burns with a pale bluish flame, when a lighted match is brought near to it. This gas is called hydrogen. The other, that produced at the positive electrode (wire coming from copper or carbon plate of battery) does not itself burn, but will re-kindle a glowing match, and cause it to burn with more than usual brilliance. This gas is known as oxygen. These two gases when left standing together do not spontaneously return to the form of water, as steam does when we allow it to cool (if, however, a light be applied to the mixture an explosion occurs, and the gases are found to have disappeared, leaving a small quantity of water as the product of their union).

If some powdered *sulphur* or brimstone be placed in a test-tube and gently heated, it will be observed to melt into a pale yellow liquid, which darkens on further heating, and becomes somewhat thick and treacly, completely liquefying again as the heating is continued. If now the hot liquid be poured out into cold water a soft substance resembling caoutchouc is obtained; throughout all these changes, however, the sulphur remains sulphur; the liquid soon passes back into the ordinary yellow solid, if allowed to cool slowly, while the soft plastic substance obtained by suddenly cooling the liquid becomes crystalline and brittle again spontaneously when kept for some time, (This substance is known as an *allotropic* modification of ordinary sulphur.) Now if, instead of heating the sulphur in a tube, it be heated in the open air, a chemical change occurs; it takes fire and forms a new substance known as sulphurous acid gas, which possesses a suffocating smell, and from which the sulphur cannot readily be recovered in its original form. It is found by further experiments that this sulphurous acid gas contains *oxygen* (derived from the air) as well as sulphur.

2. **The Effects of Heat upon Matter.**—If a few crystals of CHLORATE OF POTASH be placed in a test tube, and gently heated by means of a spirit lamp or Bunsen burner, the following series of changes will be observed:—The first effect of heating the crystals is to raise their *temperature.* If shaken out into the hand, they will be found to feel hot. (By temperature we mean "the quality of a body in virtue of which it seems hot or cold." A body which feels hot to the hand is said to be at a higher temperature than the hand.) This increase of temperature is accompanied by *expansion*, which causes the crystals to fracture with a crackling noise. On continuing to heat the chlorate of potash, a *change of state* occurs. The solid crystals melt into a clear, transparent liquid. This liquid is still chlorate of potash. If allowed to cool, it becomes solid again. If the heating be continued, however, a chemical change occurs. Bubbles of gas are seen to rapidly rise through the liquid, and this gas is found, on testing with a glowing splinter of wood, to be oxygen. What is left in the tube, when all the oxygen has been expelled, is no longer chlorate of potash, but a substance known as potassium chloride, possessing quite distinct properties, as, for instance, a different taste. This experiment, then, illustrates the four most common effects of heat upon matter, *viz.*:—(i.) **Change of temper-**

ature, (ii.) **expansion**, (iii.) **change of state**, (iv.) **chemical change.** It is desirable to consider these changes a little more in detail. We have already noted that the word temperature relates to the hotness or coldness of a body, *i.e.*, to its thermal state, or power of imparting heat to, or of taking heat from, other bodies. Two bodies are said to be of the same temperature if, when placed in contact with one another, there be no gain or loss of heat from one to the other. If, when thus placed together, one body gain and the other lose heat, the body which imparts heat to the other is said to have the higher temperature. In nearly all cases increased temperature is accompanied by expansion; and we make use of this expansion to *measure* temperature by means of a THERMOMETER, which usually consists of a fine closed glass tube, having a bulb at one end containing mercury, as shown in Fig. 20. When the bulb is heated, both glass and mercury expand, but the mercury expands much more than the glass, and consequently the mercury column rises in the tube. The thermometer is graduated by first placing it in melting ice, and marking on the stem the point to which the mercury sinks, and then immersing it in steam or boiling water, and marking the point to which the mercury rises. The distance between these two fixed points (termed the freezing point and the boiling point) is afterwards divided into an arbitrary number of equal divisions or *degrees*. In the Fahrenheit thermometer (generally used in this country), the freezing point is indicated by 32°, and the boiling point by 212°, there being thus 180° between the two. In the

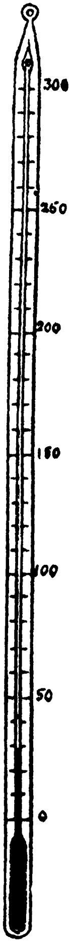

Fig. 20.

centigrade thermometer, which is almost invariably used in scientific observations, the freezing point is marked zero, and boiling point 100. It will thus be seen that a rise of 100° on the centigrade thermometer corresponds to a rise of 180° on the Fahrenheit, or the length of a degree Fahrenheit is $\frac{100}{180}$ or $\frac{5}{9}$ of a degree centigrade.[1]

We have seen that mercury and glass do not expand equally for equal increments of temperature. A simple experiment serves to show that two different metals such as steel and brass may have unequal rates of expansion. A strip of brass and a strip of steel are riveted or soldered together, and hammered out quite straight. On heating the compound bar thus formed, it bends, owing to the fact that the brass expands more than the steel, which therefore forms the concave side of the bend. The increase in length of a bar one unit long at 0°, when the temperature is raised 1°, is called the linear co-efficient of expansion for one degree; thus the co-efficient of expansion of brass is ·000016, that of iron ·000012. A bar of iron which measures 1 foot at 0° C. becomes 1·000012 feet at 1° C., 1·000024 feet at 2° C., and so on. The co-efficient of cubical expansion of a solid is approximately three times the co-efficient of linear expansion.

WATER, when near its melting point, is an important *exception* to the general rule of expansion by heat. When fresh water is cooled it contracts regularly down to the temperature of 4° C. (39° F.), but afterwards begins to expand, until in the act of freezing it increases in bulk by about $\frac{1}{10}$. Water is thus *densest* or heaviest at 4° C., and ice is lighter than an equal bulk of water, and hence floats. Owing to this peculiar property, the surface water of a cooling lake or pond sinks through the warmer water to the bottom until the temperature of 4° is reached, after which the coldest water remains at the surface until it freezes into floating ice. Were it not for this behaviour of cooling water the ice would accumulate at the bottom of lakes or rivers, and a severe winter would freeze the whole into a solid mass of ice which the summer heat might not be able to melt.

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[1] Hence the following rules:—To convert Fahrenheit readings into centigrade, subtract 32, and multiply remainder by $\frac{5}{9}$.

To convert centigrade readings to Fahrenheit, multiply by $\frac{9}{5}$, and add 32 to the product.

For example, $15^\circ \text{ C.} = (15 \times \frac{9}{5}) + 32 = 59^\circ \text{ F.}$

Temperatures below 0 are distinguished by prefixing a *minus* sign, and in calculating, this sign must be treated as in algebra.

Owing to the *expansive force* of freezing water, pipes are often burst during a severe frost, and rock masses are fractured and disintegrated by the freezing of water contained in cracks and fissures. The popular fallacy that pipes are burst by a thaw is due to the fact that no leakage is usually discovered until the thaw melts the solid plug of ice which had previously filled the pipe.

We are all familiar with the fact that matter exists in three different states or conditions: the SOLID, the LIQUID, and the GASEOUS state. A solid body, such as iron or wood, has a definite shape of its own, and possesses a considerable amount of *rigidity* or resistance to forces tending to change its shape. Liquids and gases have no definite shape of their own, but accommodate themselves to the shape of the vessels in which they are contained; they have little rigidity, offering practically no resistance to forces tending to change their shape. The term FLUID is used to include both liquids and gases. Gases are distinguished from liquids mainly by their power of indefinite expansion. If a small quantity of gas be introduced into a vacuum, the gas will spread or diffuse through the entire space so as to be uniformly distributed therein. On the other hand, a liquid, such as water or mercury, will not, under similar conditions, appreciably increase in volume, and will continue to have a free surface separating it from the space above. Gases are, moreover, much more compressible than liquids; air, for example, is 10,000 times more compressible than water.

The chief *condition* that determines the state which bodies assume is temperature. If we take some very cold ice pounded small, and apply heat to it, the ice will not immediately begin to melt, but its temperature will begin to rise, as may be seen by keeping it stirred with a thermometer. When the thermometer marks 32° F., the ice melts and becomes water, and the mercury stops rising, remaining stationary at this point until all the ice is melted. The whole of the heat received after melting begins is spent in producing change of state, and none of it in raising the temperature. If we continue the application of heat, the water gets warmer, and the mercury in the thermometer goes on rising until it reaches 100° C. At this temperature, under ordinary atmospheric conditions, the water begins to boil, and the mercury again stops rising, and remains stationary until all the water has been turned into steam or "boiled away." The fact that a great deal of heat is required to convert ice at 0° C. into water at the same temperature, or to convert water at 100° into steam at 100° was first experimentally demonstrated by Joseph Black about the year 1760, and he called this heat "**latent heat.**" It is found not only in the case of ice melting and water boiling, but in all cases of a solid passing into a liquid, and of a liquid passing into a gas; heat is similarly absorbed. If a little ether be poured into the palm of the hand, it quickly evaporates, or becomes converted into vapour, and in so doing absorbs heat from the hand, which consequently feels the sensation of cold. A thin glass vessel containing ether can be readily frozen to a wet table by blowing into it with a pair of bellows. Most liquids and some solids evaporate when exposed to the air. Those which, like ether, very readily pass into the gaseous condition are said to be volatile. On pouring a few drops of ether into a jug (warmed before the fire, or by rinsing it out with hot water) the ether quickly evaporates, filling the jug with heavy vapour, which may be poured into a number of warm glasses, and then ignited with a taper. Evaporation differs from ebullition, in that the vapour is formed at the free surface of the liquid only, and not (as in boiling) within the liquid. When steam is passed into cold water, it condenses, and in so doing gives up the heat consumed during the process of boiling: similarly the "latent heat" of a liquid is given up when it solidifies. Thus if we mix 1 lb. of water at 0° C. with 1 lb. of water at 100° C., we shall find (on testing with a thermometer) that we get 2 lbs. at 50° C., *the one pound in cooling from 100° to 50° raises the other from 0° to 50°*; if, however, we take a pound of water at 0° and pass steam into it until the temperature reaches 50°, we shall find (by weighing) that only about 1⅓ oz. of steam has been added. By experiments of this kind, conducted with certain precautions, it has been found that *the amount of heat given out by a pound of steam at 100° in condensing to* water *at 100° is enough to raise 536 lbs. of water from 0° to 1°*. The amount of heat required to raise a unit weight (say a pound) of water through 1 degree (from 0° to 1°) is called a **unit of heat**. We say, therefore, that the latent heat of steam is *536 thermal units*. Similarly the latent heat of *fusion of ice* is found to be *79 thermal units*, or it takes as much heat to convert 1 lb. of ice at 0° into water at 0°, as would raise 79 lbs. of water from 0° to 1°. It will be noticed that in defining the unit of heat we do not say a unit weight of any substance, but we specify the particular substance water; this is necessary because it is found that the *heat capacities* of equal weights of different substances vary greatly, that is, they require different amounts of heat to produce equal changes of temperature in them. One pound of water, for example, in cooling from 100° to 50° is able to raise about 30 lbs. of mercury from 0° to 50° This is expressed by saying that the **specific heat** of mercury is $\frac{1}{30}$, the specific heat of water being considered as unity. Water has a higher specific heat than any other substance, hence it takes a longer time to get hot and a longer time to cool again. It is mainly to this *high specific heat of water* that we owe the great effects of the oceanic waters in modifying climate. The specific heat of air is about 4·2 times less than that of water; hence 1 lb. of water in cooling through 1° would heat 4·2 lbs. of air through 1°; but water is about 770 times as heavy as air, therefore a cubic foot of water in cooling through a certain number of degrees would warm more than 3000 cubic feet of air through the same number of degrees. The specific heat of the land masses is, roughly speaking, $\frac{1}{4}$ that of water; moreover, the land both absorbs and radiates heat more readily than the sea, hence places near the sea have not such great EXTREMES of temperature as inland places in otherwise similar situations; the excess of summer heat being slowly absorbed and stored up in the water and given out to mitigate the winter's cold.

3. **Properties of Gases.**—It is only within comparatively recent times that men have come to understand that just as there are many different kinds of solids and liquids, so there are many distinct kinds of gases, which, though often colourless and invisible, can easily be shown to differ from one another. One of the first chemists to clearly prove this

fact was Joseph Black (some time Professor of Chemistry in the University of Edinburgh), who, in 1752, collected a peculiar gas obtained by the action of heat or of dilute acids upon ordinary limestone or chalk. To this gas he gave the name, "fixed air," because it was absorbed or fixed by lime, and by alkalies (such as potash or soda). It is now commonly known as **carbonic acid gas.** Black established the existence of this "air" in the expired breath of animals, and showed that it was present in the air evolved during fermentation. He demonstrated some of the properties which serve to distinguish this gas from ordinary air, such as its power of combining with quicklime to form chalk, and its incapability of supporting animal life. The first full account of the properties of this gas was given in 1766 by Cavendish. Some of the more important of these properties may be illustrated by the following experiments. The gas may be conveniently prepared by pouring dilute hydrochloric acid upon some lumps of marble contained in a Woolf's bottle A (Fig. 21), furnished with a delivery tube C, by which the gas can be led to the pneumatic trough D and collected over water; or the acid may be poured upon powdered chalk spread over the bottom of an ordinary pail, when the gas soon fills the pail, and may be removed by gently lowering into it a jug or bottle, from which again it may be poured into tumblers or wine-glasses. In each case its presence may be proved by means of a burning taper or candle which is at once extinguished when lowered into the gas. The weight of the gas may be further shown by pouring some of it into a glass beaker placed in one pan of a delicate balance and equipoised; it will be found that when the air originally contained in the beaker is displaced by the carbonic acid gas, the pan containing the beaker descends. Soap bubbles blown in the ordinary way will remain for some time floating upon the gas contained in a large open jar. (For this experiment, however, the gas must be free from traces of hydrochloric acid which would destroy the soap film.) If some of the gas be passed into a clear solution of lime water, the lime water is rendered milky owing to the formation of a precipitate of carbonate of lime, or chalk. This serves as the most convenient test for the presence of carbonic acid gas. If the gas be shaken up with ordinary water, some of it dissolves in the water, which acquires a slightly acid taste.

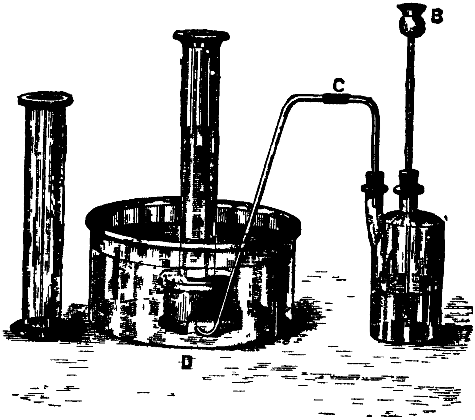

Fig. 21.

In 1766, Cavendish investigated the gas, which he called "inflammable air," now known as **hydrogen**, which, as we have already seen, is produced (together with oxygen) when a current of electricity is passed through acidulated water. This gas may be most readily prepared by pouring dilute hydrochloric or sulphuric acid upon granulated zinc, and collecting the gas as shown in Fig. 21. It is the lightest substance known, being about 14½ times lighter than ordinary atmospheric air. It can as easily be poured upwards as carbonic acid can be poured downwards, and soap bubbles, if filled with hydrogen, rise rapidly through the heavier air.

The quantity of matter contained in a unit volume of any substance is termed its **density.** The **specific gravity** of a substance is the ratio of its density to the density of some standard substance, such as water. The density of gases is usually very small compared with that of water. Thus, water is about 500 times as dense as carbonic acid gas, and more than 11,000 times as dense as hydrogen, when these gases are measured at a temperature of 0° C., and under ordinary atmospheric pressure (page 102). One litre of water under these conditions weighs 1000 grammes, a litre of hydrogen ·0896 grammes, and a litre of air 1·29 grammes.

We have seen that gases differ from liquids, in that they very readily expand and contract under variations of pressure; the relation that exists between the volume of a gas and the pressure to which it is subjected (the temperature remaining constant) was first stated by the Hon. Robert Boyle (one of the original members of the Royal Society of London) about the year 1662. He showed that (within certain limits) *the volume of a gas varies inversely as the pressure;* if the pressure be doubled the volume of the gas will be halved, if the pressure be halved, the volume of the gas will be doubled, and so on. This statement is known as **Boyle's law.** It has since been shown by the experiments of Amagat, Cailletet and others, that Boyle's law is not strictly true for any known gas, and when the pressure is very great, a considerable deviation usually occurs.

The relation that exists between the volume of a gas and its *temperature* is expressed by the **Law of Charles** (sometimes called Gay Lussac's law), which states that "a gas at constant pressure expands by the same fraction of its volume at 0° C. for each rise of temperature of one degree measured by the Mercury thermometer." This fraction is found to be very nearly the same for all gases, *viz.* $\frac{1}{273}$, so that one volume of a gas measured at 0° C. becomes $1\frac{1}{273}$ (or 1.003665) at 1°, $1\frac{2}{273}$ at 2°, and so on: the volume of a gas being, therefore, doubled when its temperature is raised from 0° to 273° C. The experiments of Regnault and others have shown that the co-efficient of expansion is not strictly the same for all gases, but the differences in the case of the more permanent gases are very small. We may roughly illustrate this law of the equal expansion of different gases by plunging two equal flasks, filled with, say hydrogen and oxygen respectively, into the same vessel of hot water (Fig. 22), and collecting the gases expelled by the heat in separate test tubes. If these be of equal size it will be seen that the water stands at the same height in each.

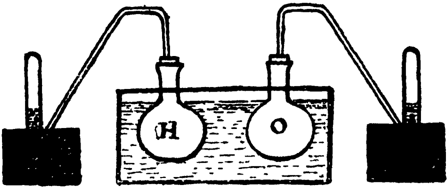

Fig. 22.

If, starting with a certain volume of gas at 0° C., the temperature is lowered, the volume will decrease by $\frac{1}{273}$ for each degree; it will thus be seen that at −273° the gas would (supposing that the law still held good) occupy no appreciable volume. This temperature is known as the *absolute zero* of the air thermometer, and temperatures reckoned from it are called "absolute temperatures." The law of Charles may then be stated thus: the volume of a gas at constant pressure varies directly as the absolute temperature. If we imagine a mass of gas whose volume has been doubled by raising its temperature from 0° to 273° C., and then compressed to its original volume without altering the temperature, we shall have, in accordance with Boyle's law, double the original pressure. Hence, it will be seen that the law of Charles may be stated in another form, *viz.*, the pressure of a gas whose volume is kept constant varies directly as the absolute temperature; and the laws of Boyle and Charles may be combined in the statement that "the product of the pressure and volume of a given mass of gas is proportional to the absolute temperature."

Boyle's law was extended by Dalton to the case of two or more different gases. When such different gases are mixed, the pressure produced by each component is independent of the rest, being determined solely by the amount of such component present in the mixture. This is sometimes expressed by saying that gases behave to one another as vacua.

Many gases when cooled to a low temperature condense into liquids, just as steam passes back into water when its temperature is lowered. By the combined action of cold and pressure, Faraday succeeded in liquefying nearly all the gases then known, with the exception of oxygen, hydrogen, nitrogen, marsh gas, carbonic oxide, and nitric oxide, which were hence styled "permanent gases." Since Faraday's time these gases (except hydrogen) have been liquefied. It is found that for every gas there is a certain temperature above which no amount of pressure, however great, will cause liquefaction; this temperature was termed, by Andrews, the **critical point.** For carbonic acid gas this critical temperature is 30·92° C., so that this gas can be condensed to a liquid by pressure alone at the ordinary temperature of the air. When the pressure is suddenly relieved the liquid rapidly re-assumes the gaseous form, and in so doing produces a lowering of temperature sufficient to freeze some of the liquid into a solid, resembling snow. The apparatus usually employed for this experiment is shown in Fig. 23.

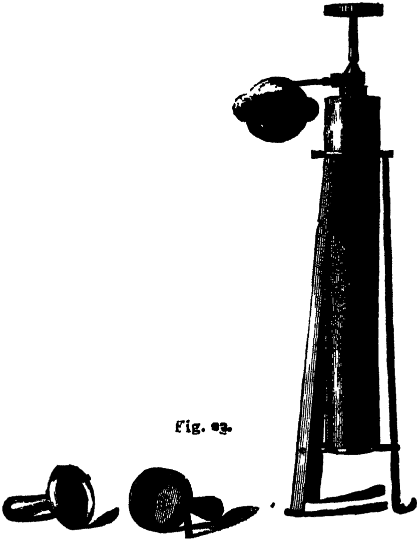

Fig. 23.

The liquid is contained in a strong steel cylinder, from which, on opening the valve, it escapes into a brass box furnished with wooden handles, in which the "snow" collects.

Oxygen was first liquefied in 1877 by Pictet, in Geneva, and (independently) by Cailletet, in Paris. In Pictet's experiments with oxygen, the gas was cooled to a temperature of—130° C. by surrounding the tube containing it with a constant supply of liquid carbonic acid, the necessary pressure being produced by the gas itself as it accumulated in the tube, which was connected with a strong retort wherein the gas was formed by the action of heat upon chlorate of potash. In Cailletet's experiments the gas was compressed in a glass tube by hydraulic machinery, and cooled by the rapid expansion due to sudden release of the pressure: under these circumstances the liquid appeared for a moment as a mist in the tube. Pictet may then be said to have used internal pressure and external cold, while Cailletet employed external pressure and internal cold. More recently, Professor Dewar (utilising the extreme cold produced by the evaporation of liquid ethylene) has obtained liquid oxygen and liquid air in much larger quantities, and has made many extremely interesting experiments with these liquids. It was found possible to preserve the liquids for some time in open vessels provided with double walls and bottoms, the space between the two being exhausted of air, and thus constituting a very perfect non-conducting vacuum jacket. Phosphorus (which is readily attacked by gaseous oxygen) when placed in the liquid (the temperature of which was 180 degrees below zero centigrade) was quite unaffected. Another very interesting fact discovered by Dewar was that liquid oxygen is attracted by a powerful magnet, and will dash up out of the vessel containing it and cling to the poles of the magnet until it disappears by rapid evaporation.

We have seen that carbonic acid gas is heavier than air, and that it can be poured from one vessel to another. Nevertheless, if a tumblerful of the gas be left open to the air for some little time it will be found, on testing with a lighted candle, that the gas has escaped, its place being taken by ordinary air. This tendency of gases to **diffuse** was investigated by Dalton in 1800, and subsequently in 1832 by Graham, who showed that *light gases diffuse more rapidly than heavy ones*, the law being that the rates of diffusion vary inversely as the square roots of the densities of the gases; for example, the relative densities of hydrogen and oxygen are as 1 to 16; the square roots of these numbers are respectively 1 and 4; the law then states that if a vessel of hydrogen be connected by a fine tube with a vessel of oxygen, the hydrogen will diffuse into the oxygen four times as rapidly as the oxygen will pass into the hydrogen. Graham found that this diffusion of gases readily takes place through such materials as unglazed earthenware and plaster of Paris. Some very striking experiments can be made by taking advantage of this fact. If, for example, the open end of a porous pot (A, Fig. 24), such as is used for galvanic batteries, be dipped into a soap solution so as to cause a film of soap to be stretched across it, the soap film will be blown out into the form of a bubble by surrounding the pot with an atmosphere of hydrogen or coal gas contained in a bell jar (B), owing to the increase of pressure due to the more rapid diffusion of the light hydrogen or coal gas into the heavier air contained in A.

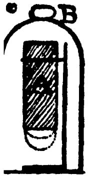

Fig. 24.

4. **The Theory of Molecules.**—When water passes into steam it increases enormously in bulk, one cubic inch of water becoming nearly a cubic foot of steam. There are two possible suppositions as to what takes place in this action. The first is that, in expanding, the material of the water spreads out so as to *completely* fill the space with steam; the second is that the matter of both water and steam is discontinuous, having a *grained* structure, and that the grains or particles are in the steam separated to greater distances from each other. Now the phenomena of diffusion and the fact that gases behave to one another as vacua (p. 60), cannot be satisfactorily explained unless we assume that such gases are composed of a number of particles separated by interspaces. These separate particles are termed *molecules*. A consideration of the phenomena of gaseous diffusion further leads us to conclude that these

particles cannot be at rest; they must be perpetually moving about with great velocity in all directions, striking against one another, and against the walls of the vessel containing the gas, and rebounding somewhat as if they were perfectly elastic balls. According to the Kinetic theory of gases (developed mainly by Clausius and Maxwell) this molecular bombardment constitutes the pressure of the gas, just as in a jet of water we may have a continuous pressure exerted by the repeated impacts of separate water particles. The amount of pressure depends upon the average number of blows falling in a given time, multiplied by the average strength or energy of each. The molecules in their path from one part of the vessel to another are continually colliding with other molecules, but the average free path is supposed to be several times the thickness of an individual molecule. If, by doubling the quantity of gas, the number of molecules in a given space be doubled, the number of impacts on a given surface in a given time will also be doubled. Thus the molecular theory accounts for Boyle's law. It is further supposed that an increase of temperature corresponds to an increased velocity of the molecules. At the absolute zero the molecules would be reduced to rest, at other temperatures the molecular agitation is proportional to the temperature reckoned from absolute zero. It can then be shown that the average energy of each blow varies directly with the temperature, so that if we increase the temperature without altering the number of molecules the pressure is proportionately increased. This, as we have seen, is one form of the statement known as the Law of Charles. The molecular theory further satisfactorily accounts for the tendency of gases to diffuse, not only into a vacuum but into a space filled with other gases, for the presence of such other gases will merely delay the penetration of the molecules into such space by increasing the number of collisions.

If we have two equal vessels, one containing, say, 1 pint of hydrogen and the other 1 pint of oxygen at the same temperature and pressure, then it can be shown by the theory that because both gases are at the same temperature the average energy of the oxygen molecules is the same as the average energy of the hydrogen molecules; since then the pressure (which is made up by multiplying the energy by the number of molecules) is the same, it follows that the number of molecules in the pint of oxygen is the same as the number of molecules in the pint of hydrogen. This is the very important principle known as **Avogadro's law**, which states that "equal volumes of all gases contain, at the same temperature and pressure, the same number of molecules." This similarity in the molecular constitution of different gases explains their equal rates of expansion.

It is supposed that in LIQUIDS the molecules are much closer together than in gases (none of them moving for any appreciable portion of their paths in straight lines), and that attractive forces between the molecules come into play. The effects of these molecular attractions are chiefly manifested at the free surface of a liquid, where the external molecules are attracted towards the interior by those behind, thus causing a "surface tension" in virtue of which a liquid behaves as if encased in a superficial film or skin like a stretched india-rubber membrane. It is owing to this tension, existing in liquid surfaces, that drops of liquid assume a spherical form, that being the shape in which the free surface is reduced to the least possible area.

In SOLID substances the molecules are supposed not to travel about from one part to another, but merely to oscillate about their mean positions.

From experiments on soap-films (which cannot be stretched beyond a certain thickness, estimated at about $\frac{1}{500,000,000}$ of an inch), as well as from other considerations, it is possible to obtain some idea of the approximate size of molecules, and Lord Kelvin concludes that *if a raindrop, the size of a pea, were to be magnified to the size of the earth, each molecule being magnified in the same proportion, the molecules would be larger than small shot, but smaller than cricket balls.*

As to the nature of the molecules of matter, perhaps the most probable hypothesis is that of Lord Kelvin, who supposes each molecule to be a rotating portion of an incompressible fluid which fills all space. This theory is based upon the results obtained mathematically by Professor von Helmholtz, with regard to the motion of vortex rings (such as the well-known smoke rings blown from the lips of a smoker), by which it was proved that if such a ring or vortex was once produced by a creative act in a perfectly incompressible fluid it would be absolutely indestructible.

5. **Properties of Liquids.**—One of the fundamental properties of fluids is that they *transmit pressure* in all directions. Thus the pressure of a column of water, due to its weight, is exerted upwards and sideways, as well as downwards. This upward pressure is easily proved by covering one end of a lamp glass with a piece of card, and plunging it into a vessel of water, as shown in Fig. 25. The pressure of the water holds the card up and keeps it pressing against the glass. If water be now poured into the lamp chimney the card falls when the water level inside and outside is the same.

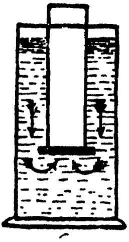

Fig. 25.

From the equality of pressure in all directions, together with the practical absence of friction in liquids, it can be shown that *when a solid is immersed in a liquid it experiences an upthrust equal to the weight of liquid displaced;* this is sometimes called the **principle of Archimedes**; it may be experimentally proved by means of a metal cylinder and a waterproof case (easily made of paraffined paper) into which it exactly fits. Placing the paper case in one pan of a balance, and hanging the cylinder from the same pan by a wire, and counterpoising, it will be found that on bringing up a vessel of water below the cylinder so as to immerse it, the equilibrium is destroyed; but it is at once restored by completely filling the paper case with water, thus showing that the upthrust on the immersed cylinder is just equal to the weight of its own volume of water.

Since the *specific gravity* of a substance (p. 58) is equal to the weight of the substance divided by the weight of an equal volume of water, it follows from the above that the sp. gr. of any solid heavier than water can be found by first weighing it in air, then weighing it in water, and dividing the weight in air by the loss of weight observed when it is weighed in water; if, for example, a piece of stone weighed 6 grammes in air and 4 in water, its specific gravity would be $\frac{6}{2} = 3$.

If water or alcohol be poured upon a flat surface it very rapidly spreads out into a thin layer; but honey or treacle will take a much longer time to do so. Such liquids, which require some *time* to yield to a shearing stress (that is, to a stress tending to move their particles over one another), are said to be **viscous.**

From the fact that liquids, however viscous, will yield to a shearing stress, however small, provided that sufficient time be allowed, it follows that, when in open vessels, liquids will be in equilibrium only when they have a level surface, for if the surface were sloping, the particles would sooner or later slide down the inclined plane under the action of gravity. Similarly in a bent tube the level of the liquid will be the same in both bends. This principle is expressed in the common statement that "water seeks its own level." We have a well-known illustration of it in the rise of water in Artesian wells, as shown in Fig. 26, where a layer of water has collected in porous sand between two beds of impervious clay. On sinking a well at A, the water will rise in the shaft and over-flow, owing to the pressure due to the height of water in the surrounding rocks.

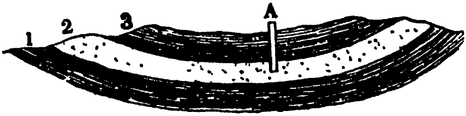

Fig 26.

We have an *exception* to the above rule in the rise of water above the surrounding level in capillary tubes and porous substances, such as sponges. Such "**capillary**" phenomena are related to the "surface tension" of liquids mentioned on page 65.

6. **Properties of Solids.**—That force which binds together the particles of a body is termed **cohesion.** In solid bodies this force is exerted to a far greater extent than in liquids. Many solids possess great **tenacity,** or resistance to forces tending to pull their particles asunder, thus a bar of steel one square inch in section will be ruptured only by a weight of from 50 to 60 tons. A body is said to be **ductile** when it can be drawn out into fibres or threads by a stretching force. Glass at a red heat is very ductile, and Professor Vernon Boys has shown that quartz or rock crystal, at a very high temperature, can be drawn into threads so fine, that a lump as big as a *walnut* would produce a thread long enough

to go *six or seven times round the world.* Bodies which can be hammered into very thin plates are said to be **malleable.** Gold (the most malleable metal) has been beaten out into leaves $\frac{1}{250,000}$ of an inch in thickness. In contrast to those bodies we have **brittle** substances, which are easily disintegrated or fractured by a blow. **Elastic** bodies are these which on being changed in form or volume by the application of force tend to recover their original form or volume. We may thus have *elasticity of bulk* and *elasticity of form.* Fluids possess elasticity of bulk only, while solids possess elasticity of form also.

The word **hardness**, as applied to solid substances, is used in somewhat different senses. Mineralogists use an arbitrary scale of hardness, in which minerals are arranged so that each will *scratch* any other mineral lower in the scale. The scale usually adopted is the following: (1) Talc; (2) Rock Salt; (3) Calc Spar; (4) Fluor Spar; (5) Apatite; (6) Adularia;[1] (7) Quartz; (8) Topaz; (9) Corundum (Emery); (10) Diamond. Bodies of hardness up to 6 (inclusive) can be scratched with an ordinary steel knife, and up to 3½ with a bronze coin; bodies of hardness 1 to 2 can be scratched by the finger nail. If a mineral be found which scratches Felspar, and is scratched by Quartz, its hardness is said to be between 6 and 7.

It is probable that *all substances,* if sufficiently cooled or heated, could be obtained in the three states of solid, liquid, and gas. M. Moissan has recently shown that in the high temperature of an electric furnace, rock crystal (the material of sand and flint) is almost instantly fused into a liquid, which in a few minutes boils vigorously, and becomes converted into vapour. This vapour, when cooled, passes back into the solid state.

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[1] A variety of felspar.

7. **Crystals.**—When a substance passes from the liquid or gaseous into the solid state, its molecules often arrange themselves in a regular manner, causing the substance to assume certain definite geometrical shapes, which, differing greatly in different substances, are usually more or less constant in substances of the same kind. A familiar example of this process of crystallisation is seen in the arborescent forms assumed by the frost on a window pane. Somewhat similar crystallisations may be artificially produced by allowing solutions of various substances, such as saltpetre or bichromate of potash, to evaporate upon clean plates of glass.

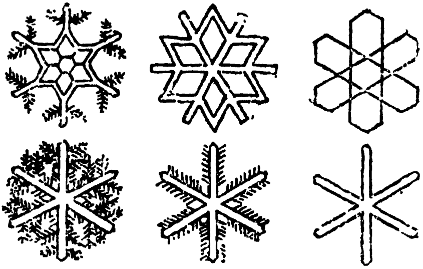


Fig. 27.

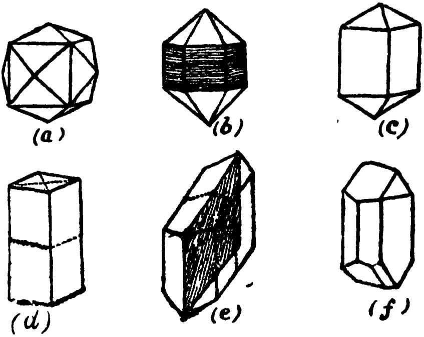


Fig. 28.

Snowflakes when examined by the microscope are found to be composed of numbers of minute ice crystals, as shown in Fig. 27. The word crystal, meaning clear ice, was first applied to the substance rock crystal (see page 97), which was imagined by the ancients to be but ice "extraordinarily hardened by a long and vehement cold." This substance is usually found in six-sided crystals, such as shown in Fig. 28 (*b*), where the parallel upright faces, marked with horizontal striations, are termed *prism planes*, and the smooth sloping faces *pyramid planes.* The relative shapes and sizes of these planes are found to differ in different specimens of rock crystal, but it was shown by Steno (a Danish physician), in 1669, that in all specimens, corresponding pairs of faces have the same inclination to one another, as shown in Fig. 29, which represents the six-sided sections obtained by cutting two different specimens of rock crystal perpendicularly to the edges of the prism planes. This may readily be proved by cutting out an angle in a piece of card, into which an angle of the crystal just fits, and showing that corresponding angles of other specimens also fit into the same card. In rock crystal the angle between each pair of prism planes is 120°.

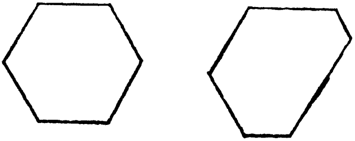


Fig. 29.

This law of the constancy of angles is found to hold generally. Bearing in mind that we do not in crystallography regard the *sizes* of the faces, but only their inclinations to one another, or, in other words, that we do not distinguish between a plane and its parallel, it is found that all known crystals may be placed in one or other of six systems, each distinguished by the degree of *symmetry* possessed by the crystals belonging to it. When a body can be divided into two by a plane, in such a way that the one half bears the

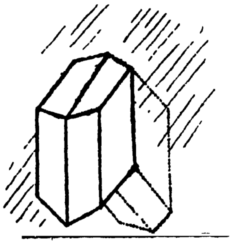


Fig. 30.

same relation to the other that an object bears to its image in a mirror, this plane is termed a plane of symmetry. The shaded portion in Fig. 28 *(e)* represents such a plane of symmetry, and it will be seen that no other plane of symmetry exists in this crystal, if, for example, we divided the crystal into two along the dotted line, the one half placed in front of a mirror would not, together with its reflection in the mirror, make up the appearance of the original crystal, but would appear as shown in Fig. 30. (Such crystals having re-entering angles do sometimes occur, and are known as *twin* crystals.)

Classifying crystals by the number of their planes of symmetry we have then the following :—

(1) TRICLINIC or ANORTHIC system (Fig. 28, *f*); no plane of symmetry.
(2) MONOCLINIC or OBLIQUE ,, (Fig. 28, *e*); one plane of symmetry.
(3) PRISMATIC or RHOMBIC ,, (Fig. 28, *d*); three planes of symmetry at right angles to each other.
(4) TETRAGONAL or PYRAMIDAL system (Fig. 28, *c*); five planes of symmetry.
(5) HEXAGONAL or RHOMBOHEDRAL system (Fig. 28, *b*); seven planes of symmetry (or three planes of symmetry, at angles of 120° to each other).
(6) CUBIC or REGULAR system (Fig. 28, *a*); nine planes of symmetry.

A little practice will soon enable an observer to tell at a glance, in simple cases, the type of symmetry to which a crystal belongs. It is a useful exercise to cut out the various forms, using a potato or turnip for the purpose. The dotted lines in Fig. 28 *(d)* show the positions of the 3 planes of symmetry in a Rhombic crystal, while the planes represented by the dotted lines in Fig. 31

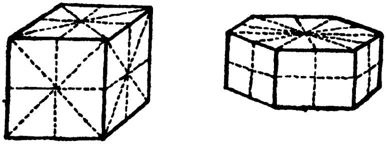


Fig. 31.

are the planes of symmetry in a crystal of the cubic and hexagonal systems respectively.

There is a definite relation between the internal structure of crystals and their external forms and symmetry. Thus most crystals break or *cleave* much more readily in certain directions than in others, and these cleavage planes are always related to the symmetry of the crystal. This property of mineral cleavage is perhaps most strikingly exhibited in MICA (the mineral popularly known as talc), which splits into thin leaves: the mineral GALENA cleaves into cubes, while, if a piece of CALC-SPAR be broken by a blow from a hammer, it will be found to break up into a number of small rhombs, which, however they may differ in size, have their faces always similarly inclined to one another.

References.—Garnett's *Heat* (Deighton, Bell & Co.); Tait's *Properties of Matter* (Black), and the smaller work by Glazebrook on *The Laws and Properties of Matter* (Modern Science Series, Kegan Paul); Clerk Maxwell's *Heat* (Longmans); and for *Crystals*, L. Fletcher's *Introduction to the Study of Minerals* (British Museum Guide); H. P. Gurney's *Crystallography* (S.P.C.K.); and Williams's *Elements of Crystallography* (Macmillan).

Section II.—The Composition of the Earth's Crust.

1. **Soils, Rocks, and Minerals.**—On examining the surface portions of our earth's crust, the first material that we most commonly meet with is ordinary vegetable **soil.** A careful inspection of such surface soil soon reveals the fact that it is made up of various materials, each possessing its own special distinctive characters. In the first place, we

can usually pick out a number of small more or less rounded stones or pebbles, as well as portions of recognisable remains of plants—dead leaves or bits of roots and stems. If now we shake up the remaining finer portion of the soil with water, it will probably be found that a fine clayey material will remain suspended for some time in the water, while a coarser sandy portion will quickly settle down to the bottom of the vessel, a further portion of the material being dissolved up in the water. Moreover, it is a matter of common observation that the soils from different parts of the country differ in their appearance and in their value for agricultural purposes, this difference being due to the varying proportions of their different constituents—some soils containing more of the sandy portion, some being very clayey, and others partly composed of limestone or of chalk. Below the surface soil we usually meet with a firmer material, sometimes showing a fairly constant character over very considerable areas. To this material, whether it be hard granite or soft clay, we give the name **Rock**. In many cases we can without difficulty detect in the rock, as in the soil, two or more different kinds of matter. Let us suppose, for instance, that the rock is a coarse-grained red GRANITE. It will in the first place be easily seen that the prevailing pink colour is due to the predominance of crystals of an opaque pink substance, that can be scratched, though perhaps with difficulty, by a knife; that splits or cleaves in two directions, generally at right angles, and has a satiny lustre upon the split faces, which are often smooth oblongs. This material is known as FELSPAR. Besides these felspar crystals, we notice spangles of a silvery-looking substance known as MICA, which cleaves very easily into thin plates, and is readily scratched with a knife, and even with the finger nail. While, lastly, we further notice the occurrence of granules of a more transparent glassy-looking substance often somewhat milky, which is so hard that it cannot be scratched with a knife, and has no tendency to split in definite directions, its fractured surfaces being quite irregular. This material is known as QUARTZ. In some other rocks, such as fine basalts, we require the aid of a microscope to satisfactorily make out the different constituents, and again in other cases it may be that the rock is essentially composed of but a single material. Since by a process of mere mechanical division we are able to obtain from soils and generally from rocks, a number of different substances, each possessing its own characteristic properties, we speak of these rocks and soils as being **mixtures**. By no amount of mere mechanical subdivision is it possible to separate the quartz or mica into different portions, each possessing different properties. All such homogeneous substances, whether natural or artificial, which, as far as mechanical division and microscopic examinations are concerned, appear to consist essentially of but one material, we may call **pure substances**, while those pure substances which occur in nature as constituents of the earth's crust the geologist terms **minerals**. A *mineral* may then be roughly defined as a "natural, homogeneous, inorganic body"; a *rock* is in most cases a *mineral aggregate*, composed of two or more different minerals: though in some few cases, as for instance, a very pure limestone or clay, the rock is composed of but one mineral substance.

2. **Mixtures and Pure Substances.**—The difference between mixtures and pure substances may be further illustrated by the following experiments:—If powdered roll-sulphur and very fine iron filings be well mixed together, the particles of iron may (by the aid of a microscope) be seen lying side by side with the particles of sulphur, and the

appearance of the mixture will vary according to the proportions in which the two constituents have been mixed; we can, moreover, easily separate the two substances in various ways. In the first place, the iron may be got out of the mixture by stirring it with a magnet, which attracts the iron but not the sulphur (in practice it will be found that some sulphur still clings to the iron, and is usually only partly removed by gently blowing upon the mass as it clings to the magnet), or, instead of a magnet, we may use an acid to dissolve up the iron, leaving the sulphur undissolved. In the second place, we can get the sulphur out of the mixture by using an appropriate solvent, such as sulphide of carbon, which dissolves up the sulphur, leaving the iron undissolved. But if we now heat in a test-tube a portion of the mixture containing by weight 7 parts of iron and 4 of sulphur, a chemical change occurs, a red glow spreads through the mass, and the sulphur and iron combine to form a black substance called sulphide of iron, which possesses properties entirely different from those possessed either by the iron or by the sulphur. Neither magnet nor sulphide of carbon has any effect upon it, while an acid dissolves it completely (with the production of a gas smelling like rotten eggs), instead of, as before, leaving a remainder of sulphur. Moreover, on examining it with a microscope, we are unable to recognise separate particles of iron and sulphur. It is, therefore, a compound pure substance, and what has occurred is an instance of **chemical combination**, a process which is distinguished by the following characteristics:—

(i.) The bodies involved combine only in certain fixed proportions, and, if mixed in any other proportions, an excess of one or the other will be left over after combination has taken place.

(ii.) The compound produced generally differs entirely from the substances which have combined to produce it.

(iii.) An evolution of heat usually accompanies chemical combination, and in some cases, as in ordinary combustion, the amount of heat thus produced is very great.

The distinguishing marks of mixtures and pure substances may then be thus summarised :—

The various constituents of a MIXTURE can (*a*) generally be more or less easily separated.

(*b*) These constituents may occur in very various proportions in different mixtures of the same material.

(*c*) The properties of the mixture are a sort of mean of the properties of its components.

A PURE SUBSTANCE (*a*) cannot in general be so easily separated into different portions, each having different properties.

(*b*) The properties of the substance are in general quite different from those of its constituents.

(*c*) Every pure substance has a fixed and definite composition, and when it can be split up into two or more simple substances, these are always obtained in certain definite proportions which never vary.

3. **Explanation of Combustion.**—One of the most familiar of chemical processes is that of ordinary burning or combustion, and it is not surprising that this process should have attracted a very large amount of attention among the chemists of the last century. It was observed that many metals, such as iron or lead, when heated in the air, became changed, the change being usually accompanied by a marked evolution of light and heat. The product of the combustion or calcination appeared to be incapable of further change. At this time chemists were guided in their thoughts about burning by the theory of a fire-substance, or phlogiston. According to this theory, all bodies capable of being burned contain a peculiar principle—the principle of inflammability, which is violently expelled when the substances undergo

combustion. It was found, however, that bodies would not burn in a space freed from air, and that when burned in a confined portion of air they lessen its quantity. This may be readily shown by burning a small piece of candle or taper stuck in a cork floating on water, and covering the whole with a bell-jar, when the water is seen to rise some little way inside the jar as the quantity of air becomes less. Further experiments showed, moreover, that substances whilst burning increase in weight. If, for example, some fine iron filings clinging to a magnet be suspended to the beam of a delicate balance and counterpoised, it will be found, on causing the filings to burn by holding the flame of a Bunsen burner or spirit-lamp underneath, that a very distinct increase of weight follows: one pound of iron, in fact, produces in burning nearly a pound and a half of a kind of iron rust, or "calx" of iron as it was then termed. Now, these facts, especially the last, could not be satisfactorily accounted for by the phlogiston theory, for if this something called phlogiston were lost by a metal when it was burned, the loss should evidently be attended by a decrease and not by an increase of weight. In 1774,

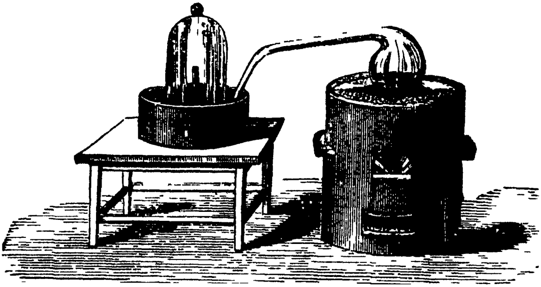


Fig. 32.

Priestley discovered oxygen gas, which he prepared by heating red oxide of mercury, and shortly afterwards Lavoisier showed that metals, whilst burning or rusting, absorbed this gas from the air, which thereby became reduced in quantity. One of the most ingenious and conclusive of the experiments by which Lavoisier arrived at this conclusion was the following:—If mercury be heated in air nearly to its boiling point for some time, it becomes corroded with red scales of rust or calx of mercury (now known as mercuric oxide). These scales, when heated more strongly, yield (as shown by Priestley) metallic mercury and oxygen gas. Lavoisier heated a known weight of mercury in a closed volume of air in order to follow out *quantitatively* the actions concerned in the process, the arrangement of the experiment being as shown in Fig. 32; and he observed that (i.) the mercury gained in weight, and the volume of air was lessened; moreover, its properties were altered: nothing would burn in it, and no animal would live in it; (ii.) the mercury obtained by subsequently heating the scales (in the manner shown in Fig. 33), when added to the mercury still left in the retort, made up its original weight, while the oxygen given off, added to the altered air, reproduced its original volume with all its original properties. Lavoisier concluded from this that the process of rusting of mercury consists in a union of the metal with oxygen, and that air contains this gas, together with an indifferent gas which takes no part in the process. Lavoisier then showed by further experiments that the combustion of ordinary fuels, as well as the rusting of metals, instead of being due to something rushing out of them, was in reality caused by the union of the burning substances with the oxygen of the air, forming products which, being in most cases colourless and invisible, give rise to the appearance of annihilation or destruction by burning, but which can be readily detected in the air by appropriate means. When pure hydrogen burns in air or oxygen, Lavoisier found that steam or water vapour was the only product of combustion, thus proving synthetically (as the experiment of passing the current of electricity through water does analytically) that water is really composed solely of oxygen and hydrogen. Pure charcoal and other forms of carbon produce only carbonic acid gas in burning, and Lavoisier thus showed that this gas is composed of carbon and oxygen. Most of our ordinary fuels are composed of both carbon and hydrogen, and hence the two principal products of their combustion are carbonic acid gas and steam, as can be readily shown by burning a candle in a clear flask, which soon becomes bedewed with moisture due to the condensa-

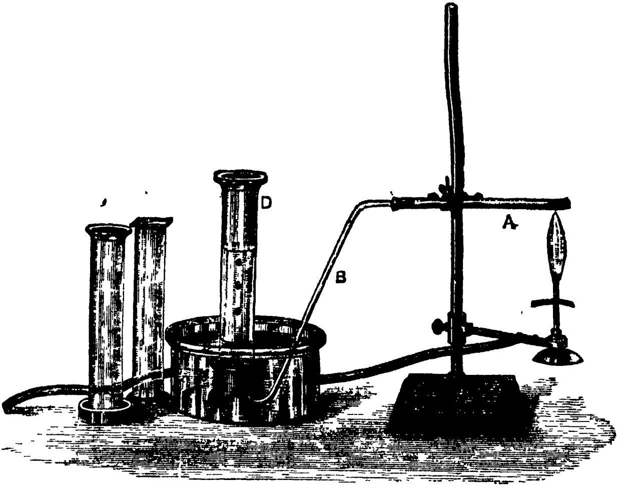


Fig 33.

tion of the steam, while the presence of carbonic acid gas may be shown by the lime-water test already described (p. 57).

4. **Conservation of Matter.**—By the use of the balance in these and other experiments, Lavoisier established the important principle that, in combustion, as well as in all other chemical changes, the materials are never, as had once been thought, really destroyed; that, however much we may change the form and appearance of things, we cannot either create or destroy a single particle of material; that matter, as measured by its weight, is indestructible. This conclusion of Lavoisier's has stood the test of all subsequent research, and is now known as the law of conservation (or indestructibility) of matter.

5. **Compounds and Elements.**—The great majority of pure substances which occur in nature, or which have been artificially produced, can, like water, be by some means or other split up into two or more parts, each having distinct properties. Such pure substances are termed *chemical compounds.* Certain other substances, such as sulphur, oxygen, hydrogen, carbon and the pure metals, have not yet been made to yield any other simpler substances. These are termed *chemical elements.* A chemical element is then "a substance from which no simpler forms of matter—that is, no forms of matter each weighing less than the original substance—have as yet been obtained." About 70 such elements are at present known. Some of these are very abundant, and occur widely distributed, while others have been found only in minute quantities. The following table shows (according to Prestwich) the approximate proportions in which the chief elements enter into the composition of the earth's crust, and gives some of the more important facts about their occurrence and properties:—

1. OXYGEN.—Forms 23 % by weight, and 21½ % by volume of the atmosphere, 88·8 % of water. A gas without smell, colour, or taste; the great supporter of life and combustion. When acted upon by electricity, becomes converted into *ozone*, an allotropic form possessing greater chemical activity, . . .	50 per cent.
2. SILICON.—Exists in sand, sandstone, quartz, etc. Never found free, but combined with oxygen, etc. The compound with oxygen is termed *silica*, .	25 ,,
3. ALUMINIUM.—A white, malleable metal; does not occur free in nature, but principally as a *silicate* in felspar and clay, ...	10 ,,
4. CALCIUM.—A yellow, ductile, malleable metal, which can be obtained from *lime*, its compound with oxygen. Limestone is carbonate of calcium, .	4·5 ,,
5. MAGNESIUM.—A white, malleable, ductile metal; not found free; burns in air with a dazzling white light; it is a constituent of *dolomite* or magnesian limestone, *Epsom salts*, *talc*, *meerschaum*, etc., ...	3·5 ,,
6. SODIUM.—A soft, bluish-white metal, lighter than water, which very readily tarnishes when exposed to the air; not found uncombined. *Common salt* is a compound of sodium and chlorine, ...	2·0 ,,
7. POTASSIUM.—Discovered by Davy in 1807; not found free. A soft, bluish-white metal, resembling sodium. A constituent of *saltpetre*. Is very widely diffused, occurring in plants and animals, as well as in many minerals, such as *potash felspar*,	1·6 ,,

8. CARBON.—Occurs in the three allotropic forms of *diamond*, *graphite*, and *charcoal*. Coal is an impure form. It is a constituent of limestone and chalk,	2·4 per cent
9. IRON.—The most useful metal. Rarely found native. Most commonly occurs combined with oxygen (*hæmatite*, *magnetite*, etc.), or with sulphur (*iron pyrites*), ...	
10. SULPHUR.—A yellow brittle solid, found free in volcanic regions; also combined with metals forming *sulphides*, and with metals and oxygen, forming *sulphates*, ...	
11. CHLORINE.—Discovered by Scheele, 1774, and found to be an element by Davy, 1810. A yellow-green gas obtained from common salt, etc. Possesses strong bleaching properties, and acts readily upon many metals, ...	
12. Other elements (*See* table on page 96), . .	1·0 ,,
	100·0

6. Metals and Non-Metals.—If one end of a rod of iron or of copper be held for a short time in a flame, it will soon be found that the heat passes along the rod, and causes its other end to become hot. Such passage of heat along a rod is called *conduction* of heat. A rod of charcoal or of sulphur will not conduct heat readily in this way; one end of the charcoal or sulphur may be actually burning vigorously, while the other end remains quite cool. This difference of behaviour is expressed by saying that iron and copper are good conductors, and charcoal and sulphur bad conductors of heat. Similarly, if a rod of copper, and an electric bell, be introduced into the circuit of a galvanic battery, the ringing of the electric bell will show that the electric current can readily pass through the copper; while on removing the copper and substituting a rod of charcoal the bell at once ceases to ring, charcoal not being a good conductor of electricity. Those elements which readily conduct heat and electricity usually also possess a peculiar kind of lustre, and are called **metals**. The remaining elements have (with the exception of graphite and iodine) no such "metallic" lustre, and are termed **non-metals**; there is, however, no exact line of demarcation between the two classes.

In the electrolysis of water described on page 47, we noticed that the hydrogen appeared at the negative, and the oxygen at the positive electrode. Hence as "electricities of opposite sign attract each other," hydrogen is termed an **electro-positive** element, and oxygen an **electro-negative** element. Many other compounds may be similarly split up by passing a current of electricity through them when in a state of fusion or solution (as in the processes of electro-plating and electro-typing), and it is then found that when a compound of a metal and a non-metal is electrolysed the metal always appears at the negative, and the non-metal at the positive pole. Thus, if the current be passed through chloride of copper, metallic copper is deposited at the negative, and chlorine gas escapes at the positive electrode. *The metals are therefore electro-positive* with regard to the non-metallic elements.

7. **Acids, Bases, and Salts.**—The metals and the non-metals are further distinguished by their chemical characters. When sulphur or phosphorus is burned in oxygen the compound produced (termed an oxide) is found to be **acidic**, that is, it will react with water to produce an acid. Acids are compounds containing hydrogen, which usually have a sour taste, which change the colour of certain vegetable substances, such as a solution of blue litmus to red, and

which interact with metals and metallic oxides to produce compounds termed **salts.** The oxides of iodine, chlorine, and other non-metallic elements are acid-forming oxides. On the other hand, when metals, such as magnesium, zinc, potassium, etc., burn in oxygen, they produce oxides which are termed **basic-oxides**, or bases. Some of these basic oxides, such as potash and soda, dissolve in water producing **alkaline** liquids which are directly opposed to acids in their chemical action. They restore the blue colour to litmus solutions reddened by acids, and destroy the acidity or sourness of these bodies. When a basic oxide reacts with an acid to produce a salt, the acid is said to be neutralised by the base. The salt does not in general exhibit the properties of either acid or base. The relation between the composition of acid and salt is expressed by saying that the hydrogen of the acid is wholly or partially replaced by a metal. Thus, if we burn a piece of the metal magnesium in air or oxygen, we get a white powder known as magnesia or oxide of magnesium as the product of its combustion; this powder will be found to be slightly alkaline, restoring the blue colour to moist litmus paper reddened by an acid. Now, if we dissolve this magnesia in the smallest possible quantity of dilute sulphuric acid, we get the neutral salt, sulphate of magnesia (or Epsom salts) left in solution, which may be obtained in the solid form by evaporation. The same salt is formed when the metal magnesium is dissolved in sulphuric acid: in this case the hydrogen of the acid escapes free, in the former case it combines with the oxygen of the magnesia to form water. All acids are, as already noticed, compounds of hydrogen, but all compounds of hydrogen are not acids. Most acids are compounds of hydrogen with oxygen and another non-metallic element; a few contain no oxygen and a few are compounds of metals with hydrogen and a relatively large quantity of oxygen.

8. **Classification of Chemical Reactions.**—The chemical change occurring when iron and sulphur are heated together is, as we have seen, a case of **simple combination.** When a current of electricity is passed through acidulated water (page 47) we have an instance of **simple decomposition,** the compound substance water being split up or decomposed into its component elements. The great majority of chemical reactions do not consist of these two simple processes, but of a re-arrangement of the component elements of the bodies which act on each other. For instance, when the metal zinc acts on dilute sulphuric acid it dissolves, hydrogen is evolved as a gas, and another substance—sulphate of zinc—is formed. The zinc is said to have replaced or turned out the hydrogen from the acid, and the reaction is termed a **simple replacement.** Again, when a solution of common washing soda (sodium carbonate) is added to a solution of gypsum (sulphate of lime) a white precipitate of chalk (carbonate of lime) is formed, and Glauber's salt (sodium sulphate) is left in solution. We have at first sodium carbonate and sulphate of lime, and by a process of exchange we get sodium sulphate and carbonate of lime. Such a process of exchange is called a **double decomposition.**

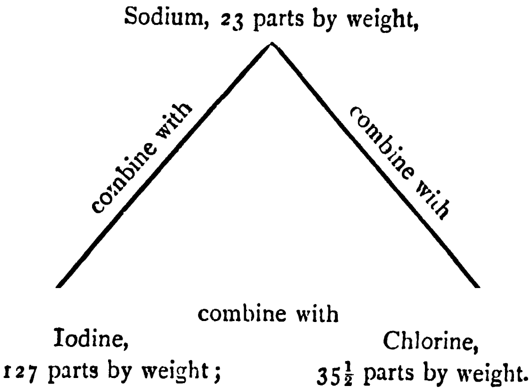
9. **The Laws of Chemical Combination.**—It has already been stated that every pure compound substance consists of certain elements, combined in certain definite proportions which never vary. This statement is known as the **Law of Definite Proportions.** Two other important laws with respect to chemical combination were established by the English chemist, John Dalton (born, 1766; died, 1844). In 1802 Dalton was investigating the action of air upon a

gas, now known as NITRIC OXIDE, in presence of water, and he noticed that the oxygen contained in one hundred volumes of air united either with 36 or with 72 volumes of nitric oxide, leaving a residue of pure nitrogen. He concluded, therefore, that oxygen combined with a certain quantity of nitric oxide, or with double that quantity, but not in any intermediate quantities. In 1804, he found that the same law was observed in the case of the union of oxygen and carbon. We have already described the preparation of the gas known as carbonic acid gas. Now, Priestley had discovered another gas composed of carbon and of oxygen, *viz.*, CARBONIC OXIDE; and Dalton found that carbonic acid gas contains, for the same weight of carbon, just twice as much oxygen as is contained in the carbonic oxide, and, as before, he found it to be impossible to get any intermediate compound containing less than double the quantity of oxygen (this fact explains the terms *carbon monoxide* and *carbon dioxide* often given to these gases). Carbon monoxide may be readily formed by heating in a test tube a mixture of strong sulphuric acid and formic acid; it will then be observed that on applying a light to the mouth of the tube the gas *burns* with a bright-blue flame, in this respect differing entirely from carbon dioxide.

Many other instances of the same kind might be given, and we therefore conclude that *if two elements combine in more proportions than one, so as to form more than one compound, the proportions of the elements in such compounds are simple multiples of each other*—**(Law of Multiple Proportions).**

It was further found that *the weights of two different elements, which severally combine with one and the same weight of a third element, are also the weights of those different elements which combine with each other*, or they bear a simple relation to these weights — **(Law of**

Reciprocal, or Equivalent, Proportions). For example, it is found that 35½ parts by weight of chlorine combine with 23 parts of the metal sodium to form sodium chloride or common salt, and that 127 parts of iodine combine with the same weight (23 parts) of sodium to form a compound known as sodium iodide; if now it be found that chlorine and iodine can combine with each other, then the law asserts that the numbers 35½ and 127 (and numbers simply related thereto) should represent the proportions in which they do combine. Two such compounds of chlorine and iodine are actually known, one of which contains 127 parts of iodine combined with 32½ parts of chlorine, and the other 127 parts of iodine combined with 3 times this amount, or 108 parts of chlorine. These facts may be represented graphically thus:—



To these three laws, with regard to chemical combination, may be added a fourth—the **Law of Volumes** discovered by Gay Lussac, which states that when *gases* combine together they do so in *equal volumes or in volumes which* *have some simple relation to each other;* thus we have seen that two volumes of hydrogen unite with one volume of oxygen to form water. Similarly one volume of hydrogen always unites with one volume of the gas chlorine to form two volumes of the compound gas, hydrochloric acid; and two volumes of carbon monoxide unite with one volume of oxygen to form two volumes of carbon dioxide, and so on.

A consideration of these laws will show that we are able to attach to each element a *number* which expresses the proportion in which it enters into any compound, or needs only to be multiplied by some small number to express this proportion. These numbers are only relative, and as hydrogen is taken as the standard, the number for hydrogen is made unity.

10. **The Atomic Theory.**—In order to give some explanation of these facts, Dalton propounded his atomic theory. According to this theory all elements consist of a number of small particles called **atoms**, which are indivisible, or, at any rate, which never split into parts in chemical reactions. The atoms of the same element are alike in every respect. The atoms of different elements have different weights and different properties, but the relation between their weights is given by the numbers which we are able to attach to the elements as expressing the proportions in which they enter into chemical combination. When two or more elements combine it is assumed that this combination consists in the approximation or union of the different atoms one to another, such union being conveniently regarded as due to the action of some force which we term **chemical affinity.** Having made these assumptions Dalton was able to explain why compounds must contain their constituent elements in the combining proportions or in multiples of them, and in no intermediate proportions. For example, one atom of

carbon may unite either with one atom of oxygen or with two atoms of oxygen, and in each case we get a perfectly distinct body of definite composition; and (since the atom is the smallest portion of an element which can take part in any chemical action) there can be *no intermediate stages* corresponding to the gradual increase in the proportion of one or other constituent such as may occur in the case of a mixture.

In Dalton's nomenclature the term atom was applied to elements and compounds alike, but it will at once be seen that in speaking of an atom of water and of an atom of oxygen or hydrogen, we are using the word in two somewhat different senses; in the case of the water we are referring to a small particle known to be divisible into still smaller particles of its constituent elements, while the atoms of these elements are particles which do not appear, so far as our present knowledge goes, to be divisible into smaller particles. We now give the name of **molecules** to the small particles of water formed from the two atoms of hydrogen and one of oxygen. The molecule of water is then the *least quantity* of the substance which can exist as such, and which, if still further divided, is no longer water, but the individual atoms of oxygen and hydrogen of which the water molecule was built up. The molecule of a compound may be defined as the "smallest quantity of any substance which exhibits the properties of that substance, and which cannot be split into parts without destroying those properties." The molecule is built up of still smaller particles, each of which is called an atom.

It is not quite so easy to see that the molecule of an *element*, defined as above, or otherwise as the smallest mass of that element which can exist by itself or in the free state, is usually composed of two or more atoms. If we consider the *fact* that one volume of hydrogen combines with one volume of chlorine to form two volumes of hydrochloric acid gas, and accept at the same time the *theory* that these elements combine atom to atom, it is clear that *some simple relation* must exist between the volumes and the number of atoms in these volumes. Gay Lussac stated the relation thus:—"Equal volumes of gases contain (under like conditions) an equal number of atoms." Dalton rightly rejected this conclusion, for it will be seen that if this were so one atom of hydrogen must, in the case we are considering, have combined with one atom of chlorine to form two "compound atoms" of hydrochloric acid, and, therefore, the single "atom" of hydrochloric acid must be composed of only half an atom of hydrogen and half an atom of chlorine, but this statement does not agree with our definition of the atom of an element. Avogadro modified the Daltonian theory by introducing the conception of two different orders of small particles—atoms and molecules—and modified Gay Lussac's theory into the statement known as Avogadro's law, *viz.*, that *equal volumes of gases contain* (under like conditions of temperature and pressure) *an equal number of molecules*, a statement which we have already seen can also be deduced from simple physical considerations. Thus the molecule of hydrogen, or the smallest amount of this substance which can exist in the free state, is a dual structure, consisting of at least two atoms, and the action which takes place between hydrogen and chlorine really consists in a molecule of hydrogen (containing two atoms) uniting with a molecule of chlorine (also containing two atoms) to form two molecules of hydrochloric acid, each consisting of one atom of hydrogen united to one of chlorine. This statement, it will be observed, accords with Avogadro's law, and with the experimental fact that one volume of hydrogen unites with one volume of chlorine to form two volumes of hydrochloric acid. It follows from Avogadro's law that the relative weights of equal volumes of gases represent the relative weights of the molecules of which these gases consist.

11. **Chemical Nomenclature and Notation.**—The names given to the *elements* generally express some marked chemical or physical *property*, or indicate the *source* from which they are obtained; thus OXYGEN, meaning "*acid producer*," was so called by Lavoisier because it was thought that all acids contained this element; HYDROGEN, the "*producer of water*," received its name as being one of the constituents of this substance; IODINE, from the Greek, *iōdes—violet*, refers to the characteristic violet colour of the vapour of this element; BERYLLIUM signifies that this metal is a constituent of the gem known as beryl: and STRONTIUM that the element occurs in *strontianite*, found at Strontian in Argyleshire. Many of the names, especially the older ones, are, however, purely fanciful, as MERCURY and SELENION (*selēne*—the moon). It may be noted that the termination *um* always signifies a metal.

The names of *compounds* are intended to indicate their composition. All compounds of two elements only (sometimes called *binary* compounds) have names ending in *ide*. Thus the compounds of oxygen with another element are termed *oxides*, those of sulphur, *sulphides*, of chlorine, *chlorides*, and so on; the termination *ide* being added to the name (usually abbreviated) of the more negative or non-metallic element. Thus we usually say hydrogen chloride, and not chlorine hydride. When two oxides, chlorides, etc., of the same element are known, the terminations *ous* and *ic*, applied to the modified name of the more positive element, indicate respectively a relatively less or greater amount of the more negative element; thus *ferrous* oxide is an oxide of iron, containing relatively less oxygen than is contained in *ferric* oxide. (The prefix *hypo* expresses relatively less oxygen than that of the oxide ending in *ic* or *ous*, while the prefix *per* indicates that oxide of a series which has most oxygen.) In the nomenclature of many compounds of three or more elements, the same prefixes and terminations are used in a similar manner, thus *sulphurous acid* is a compound of hydrogen, sulphur and oxygen, containing, for the same weight of hydrogen and sulphur, less oxygen than is contained in *sulphuric acid*. The terminations *ite* and *ate*, applied to salts, correspond respectively to the terminations *ous* and *ic*, applied to the acids. Thus, when *sulphurous* acid acts upon a metal, the salt produced is termed a *sulphite*, while the action of *sulphuric* acid would produce a *sulphate*. CHEMICAL NOTATION aims at abbreviating names by means of symbols and formulæ. The **symbols** of the elements usually consist of the first letter or letters of their Latin names, thus O stands for oxygen, C for carbon, Fe *(ferrum)* for iron, K *(Kalium)* for potassium. These letters are further made to indicate a single atom of each element, so that H stands always for one part by weight of hydrogen, C for 12 parts of carbon, O for 16 of oxygen, and so on. Compounds are represented by placing together the symbols of their constituent elements, thus, water which consists of one atom of oxygen united to two of hydrogen is represented by the **formula** H_2O. Sulphuric acid, containing two atoms of hydrogen united with one of sulphur and four of oxygen is indicated thus—H_2SO_4.

The reaction of two or more substances is represented by a **chemical equation**: for example, the equation $2\ HgO = 2\ Hg + O_2$ is an abbreviated way of expressing the fact that

432 parts by weight of mercuric oxide may be split up into 400 parts of mercury and 32 of oxygen. Again, the action of sulphuric acid upon zinc to produce hydrogen and zinc sulphate may be represented by the equation,

$$Zn + H_2SO_4 = ZnSO_4 + H_2$$

Here Zn stands for one atom of zinc—weighing 65; H_2SO_4 for one molecule of sulphuric acid—made up of two atoms of hydrogen (weighing 2), one of sulphur (weighing 32), and four of oxygen (weighing 4 times 16 or 48), thus:—

$$\underbrace{\begin{array}{c}Zn\\65\end{array} + \begin{array}{c}H_2SO_4\\\underbrace{2+32+64}_{98}\end{array}}_{163} = \underbrace{\begin{array}{c}ZnSO_4\\\underbrace{65+32+64}_{161}\end{array} + \begin{array}{c}H_2\\2\end{array}}_{163}$$

12. **Classification of the Chemical Elements.**—The English chemist, Newlands, in 1864, drew attention to the fact that the properties of the elements varied *periodically* with their atomic weights, that is, the properties vary with the atomic weights, but *recur* at certain periods. Thus, if the 14 elements from Lithium to Chlorine be arranged in *two series of seven* in each, thus:—

Li = 7	Be = 9	B = 11	C = 12	N = 14	O = 16	F = 19
Na = 23	Mg = 24	Al = 27	Si = 28	P = 31	S = 32	Cl = 35·5

it will be seen that the mean difference in the values of the atomic weights of *consecutive* elements is about 2; and of *elements placed under one another* about 16, and further that there is a *similar gradation of chemical properties* in each of these series, the first member of each being a strongly positive metal, and the last a strongly negative non-metal. This arrangement may be extended with like results to the whole of the known elements, if it is assumed that there are several gaps in the list, and if, further, about a dozen elements be placed somewhat irregularly in an eighth division. (*See* table.)

By means of this Periodic Law, the Russian chemist, MENDELÉEF, was able to predict the existence and properties of gallium, scandium, and germanium.

These remarkable relations of the chemical elements to one another seem to suggest that they may really be of a compound nature, having been evolved from one primal element. This hypothetical substance has been termed by Crookes—protyle (pro—*earlier than*, and hyle—*stuff or matter.*)[1]

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[1] *See* Crookes' Address to Chemical Section of British Association. Birmingham, 1886.

Table giving the *names, symbols,* and approximate *atomic weights* of the elements arranged according to the PERIODIC LAW.

	I	II	III	IV	V	VI	VII	VIII
1 2	Hydrogen H 1 Lithium Li 7	Beryllium B 9	Boron B 11	Carbon C 12	Nitrogen N 14	Oxygen O 16	Fluorine F 19	—
3 4	Sodium Na 23 Potassium K 39	Magnesium Mg 24 Calcium Ca 40	Aluminium Al 27 Scandium Sc 44	Silicon Si 28 Titanium 48	Phosphorus P 31 Vanadium V 51	Sulphur S 32 Chromium Cr 52	Chlorine Cl 35.5 Manganese Mn 55	Iron Fe 56 Nickel Ni 58.6 Cobalt Co 59
5 6	Copper Cu 63 Rubidium Rb 85	Zinc Zn 65 Strontium Sr 87	Gallium Ga 69 Yttrium Y 89	Germanium Ge 72 Zirconium Zr 90	Arsenic As 75 Niobium Nb 94	Selenium Se 79 Molybdenum Mo 96	Bromine Br 80 (100)	Rhodium Rh 104 Ruthenium Ru 104.5 Palladium Pd 106
7 8	Silver Ag 108 Caesium 133	Cadmium Cd 112 Barium Ba 137	Indium In 114 Lanthanum La 139	Tin Sn 118 Cerium Ce 140	Antimony Sb 120 Didymium Di 144	Tellurium Te 125 Terbium Te 148	Iodine I 127 Samarium Sm 150	152—156, 3 elements
9 10	<—— ? 170	? 4 element ? 172	156 to 162 Ytterbium Yb 173	——> 178	Erbium Er 166 Tantalum Ta 182	? 167 Tungsten W 184	? 169 ? 190	Osmium 190.3 Iridium Ir 192.5 Platinum Pt 104
11 12	Gold Au 197 224 ?	Mercury Hg 200 Masrium Ms 228 ?	Thallium Tl 204 230 ?	Lead Pb 207 Thorium Th 232	Bismuth Bi 208 ? 237	<—— ? 2 elements Uranium U 240	——> 212 to 220 ? ? 245	

13. **Common Rock Forming Minerals.**—The three simple minerals—Quartz, Felspar, and Mica—which make up the rock *Granite*, have been already partially described (page 74). The substance known as Rock Crystal, referred to on page 70, is a common form of Quartz. Chemically, this mineral is composed of *Silica*, or the oxide of the non-metallic element Silicon, its formula being SiO_2: while Felspar and Mica are both complex silicates, or compounds of Silica with various bases. A few of the more important facts about the composition and properties of some of the minerals which are important, either as constituents of common rocks, or as *ores* of the useful metals, are shown in the table (pages 98 and 99). Altogether, some 800 different minerals are recognised by mineralogists, but the greater number of them are comparatively rare. It has been calculated that the minerals Quartz and Felspar together make up more than 80 per cent. of the rocky crust of the earth.

References.—Muir's *Chemists* (Heroes of Science Series. S.P.C.K.)
Cooke's *New Chemistry* (International Science Series).
Hatch's *Mineralogy* (Whittaker & Co.).

TABLE OF SOME OF '

NOTE.—The letter H signifies hardness, as d

CRYSTALLINE SYSTEM.	TRICLINIC.	OBLIQUE.	RHOMBIC.
I. NATIVE ELEMENTS. A. Metals.			
B. Non-Metals.		GRAPHITE. "Black lead," a form of carbon. H = about 1; crystals are 6-sided tables.	SULPHUR. Reco by its pale yello our. H=1½—2½
II. SULPHIDES.			MARCASITE. I same compositic Pyrites, but pa colour.
III. CHLORIDES and FLUORIDES.			
IV. OXIDES.			
V. CARBONATES.			ARAGONITE has composition as (but is sensibly and heavier. F 4; G=3.
VI. SULPHATES.		SELENITE or GYPSUM. $CaSO_4 + H_2O$; very soft (H=1½—2), crystals often like Fig. 28 (c).	BARYTES. (Heav $BaSO_4$; general or yellowish, G=4½; H=3½.
VII. SILICATES.	PLAGIOCLASE FELSPARS Silicates of Al and K, Na or Ca. *Microcline.* Same composition as Orthoclase. *Albite.* Soda felspar. *Anorthite.* Lime felspar. *Oligoclase* and *Labradorite.* Soda lime felspars. H=6; G=2·6 to 2·7.	ORTHOCLASE FELSPAR. $K_2Al_2Si_6O_{16}$; white, grey, or pink. (See page 74.) MICA. A group of complex silicates of Mg, Al, K, etc.; distinguished by cleaving into elastic laminæ. HORNBLENDE and AUGITE. Silicates of Mg, Ca, and Fe; usually black in colour. H=5—6; G=2·9—3½. *Asbestos* is a fibrous variety	OLIVINE. Sil Iron and M. usually found i irregular gra liable to chan *serpentine.* Some varieties o BLENDE and A

MORE IMPORTANT MINERALS.

on page 69. G means specific gravity (approximate).

HEXAGONAL.	PYRAMIDAL.	CUBIC.
		GOLD. Generally found in quartz, ı pure; very soft (H=3) and malle very heavy. G=about 19. **SILVER.** Very malleable and du G=10½. **PLATINUM.** Usually in grains. H=4 G=18. **COPPER.** Generally in irregular ma G=8½. **DIAMOND.** Crystals often rounded; fect octahedral cleavage. H=10; G:
CINNABAR. HgS; the principal ore of Mercury; colour, bright red. H=2–2½; heavy. G=8.	**COPPER PYRITES.** $CuFeS_2$; distinguished from Iron Pyrites by its darker colour and less hardness, and from gold by its brittleness. The most abundant ore of copper. H=3½–4; G=4.	**PYRITES.** FeS_2; yellow metallic c H=6–6½ (distinction from gold) G **GALENA.** PbS; most common o lead; generally in lead-grey c cubical cleavage. H=2½; G=7½. **BLENDE.** ZnS; important ore of generally brown or black, with bril lustre. H=3½–4; G=4.
		ROCK SALT. $NaCl$; usually in c colourless or white when H=2–2½; G=2. **FLUOR SPAR.** CaF_2; purple va known as Blue John. Usually t parent cubes, with octahedral clea H=4; G=3.
HÆMATITE. Fe_2O_3; dark steel colour, brilliant lustre. H=5½–6½; G=5·2. **QUARTZ.** SiO_2; recognised by its hardness (H=7) and glassy lustre. Jasper, cairngorm, chalcedony, are varieties.	**TINSTONE.** SnO_2; the most important ore of tin. Crystals like Fig. 28 (c). Usually brown or black. H=6–7; G=7	**MAGNETITE.** Fe_3O_4. Magnetic (of iron; usually in iron-black oct rons; distinguished by its magnetic perties. H=5½–6½; G=5. (The *stone* of the ancients.)
CALCITE or CALC SPAR. $CaCO_3$; great number of crystal forms, as dog tooth spar, Iceland spar, etc. Effervesces with acid. H=3; G=2·7. **CHALYBITE.** $FeCO_3$; important ore of iron; colour, buff. H=3½–4½, G=3·8		
NEPHELINE. Silicate of Al. and Na. with some K.	**LEUCITE.** A silicate of Al and K. Common in Vesuvian lavas.	**GARNET.** A group of several min differing in composition, colour, Common in schists.

Section III.—The Earth's Atmosphere.

1. **The Weight of the Air.**—The very familiar fact that water rises in an ordinary syringe or pump when the piston is drawn up, was "explained" by the ancient philosophers in the statement that "Nature abhors a vacuum." When, however, it was found by Galileo that, even with the best vacuum obtainable, the water in a common pump would not rise to a greater height than about 32 feet, this statement was seen to be both inadequate and incorrect; it might be that Nature abhorred a vacuum, but at any rate, that abhorrence ceased in the case of a vacuum more than 32 feet in height. Galileo's pupil Torricelli appears to have been the first to conceive the idea that what really caused the water to rise in a pump was the pressure of the air (due to its weight) on the surface of the water outside, and that the reason why the water could be forced up to a certain height only, was that the column of water in the pump tube then balanced the air column pressing upon the surface, the two columns, the water going up 30 odd feet on the one side, and the air column an unknown number of miles on the other, being of the same weight. Now, quicksilver or mercury is a liquid 13 times as heavy as water, and Torricelli argued that if a column of water can be sustained in a vacuum to a height of about 32 feet, a column of mercury should be kept up to a height of but one-thirteenth of this amount, *viz.*, about 30 inches. This Torricelli found to be actually the case. Taking a glass tube (Fig. 34) about 3 feet long, open at one end only, he filled it with mercury, and stopping up the open end with his finger, turned it upside down, plunging the end, closed with the finger, beneath the surface of a further quantity

of mercury contained in a basin or cistern. On withdrawing the finger he then observed that the mercury in the tube fell until it rested at a height of about 30 inches above the level of the mercury in the basin, leaving an empty space in the top of the tube, which has ever since been known as the "Torricellian vacuum." This tube, containing mercury inverted in a basin of mercury, was afterwards called by Boyle a **barometer**, *i.e.* measurer of weight or pressure, and we usually think of it as a weather glass, because it has been found by experience that changes in the atmospheric pressure are usually associated with changes in the weather. Pascal first suggested the experiment of carrying the barometer to the top of a mountain, arguing that if Torricelli's theory were correct, the mercury ought to further sink in the tube, since part of the air column being left below, the pressure (due to the remainder) would naturally be less. An ascent of the Puy de Dome by Perrier, showed that this was the case, the mercury standing 3 inches lower at the top of the mountain than it did at the bottom, thus proving conclusively that it really was the pressure of the air which supported the mercury column. At about $3\frac{1}{2}$ miles above

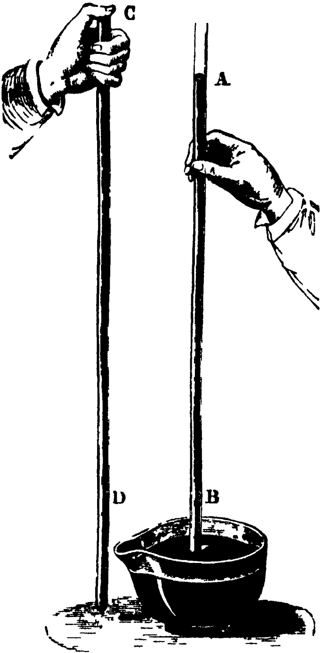

Fig 34

sea-level, the mercury in the barometer falls to 15 inches, or, in other words, at that height the density of the air is reduced to one-half the density at the sea-level. It follows from the law of gaseous pressure that at a height of 7 miles the density is $\frac{1}{4}$ that at the sea-level, at $10\frac{1}{2}$ miles $\frac{1}{8}$, and so on, the density decreasing in geometrical progression as the height increases in arithmetical progression; this is found by observation to be the case; we can infer that at a height of 40 miles, the atmospheric density would be only $\frac{1}{2000}$ of what it is on the surface of the earth. If a barometer tube be made of exactly one square inch section, it is clear that if the mercury stands at a height of 30 inches, the pressure of the air will be sustaining the weight of 30 cubic inches of mercury; this amount of mercury is found to weigh about 15 lbs. Hence the pressure of the air on one square inch of surface at the sea-level is about 15 lbs.

A few years after the discovery of the barometer, Otto von Guericke, burgomaster of Magdeburg, invented the **air-pump**, an instrument by which the air can be drawn out of a vessel, leaving it almost empty. By means of this pump he abstracted the air from a hollow metal globe made of two hemispheres fitted tightly together and furnished on the outside with rings by which they could be pulled apart, and he found that so long as there was air inside the globe the two halves came apart very easily, but that when the greater part of the air had been pumped out so as to leave a vacuum inside, it required immense strength to overcome the great pressure of the outside air which forced them together.[1] The experiment has always been called "the experiment of the Magdeburg hemispheres." The great pressure of the air can be strikingly illustrated without the use of an air pump, by the simple expedient of boiling a little water in a tin can so as to drive out the air and fill it with an atmosphere of steam. On then tightly corking the can, and pouring cold water on the outside so as to condense the steam, a partial vacuum is formed inside the can, which being left without sufficient internal support is crushed up by the atmospheric pressure of 15 lbs. on every square inch of its external surface.

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[1] If the hemispheres are 1 ft. in diameter, this pressure will be nearly a ton.

2. **The Extent of the Air.**—From the fact that *meteorites* (which owe their luminosity to the heat developed by the friction produced by their rapid passage through the air) have been observed at a height of 200 miles or more above the earth's surface, we conclude that in an attenuated form the atmosphere extends at least to that height. Air is probably, however, sensibly present to the barometer to a height of only about 40 or 50 miles. It has been calculated that above the height of 300 miles the air must be so rarefied that there can be only one molecule per cubic foot, and since under these conditions the molecules can probably travel for millions of miles without colliding with one another, it appears that particles must be continually lost from our atmosphere as the earth travels through the regions of space, other particles (not necessarily of the same composition) being perhaps gained from these regions.

3. **The Composition of the Air.**—We have already seen that the researches of Lavoisier showed that the air is mainly composed of oxygen and nitrogen. The relative *proportions* of these two gases in air can be roughly shown by burning phosphorus in a limited supply of air contained in a jar inverted over water. The phosphorus unites with the oxygen to form white fumes of an oxide of phosphorus, which being soluble, dissolves in the water, forming a solution of phosphoric acid. The water soon rises (owing to atmospheric pressure) to fill the space thus left,

which is found to be about $\frac{1}{5}$ of the total volume of the jar. The oxygen may be more gradually removed by letting the phosphorus oxidise slowly without setting fire to it, or by suspending a muslin bag filled with moist iron filings in the jar, and leaving them to absorb oxygen in the process of rusting, or we may make use of liquids such as *pyrogallate of potash* or *cuprous chloride,* which have the power of absorbing oxygen. The gas which remains, after the removal of oxygen from the air, is characterised by properties quite distinct from those of the oxygen. It does not burn when heated in air, and ordinary burning bodies are at once extinguished when placed in it. Its use in the air appears to be to dilute the oxygen, just as spirits may be diluted with water. That the oxygen and nitrogen of the air are only *mechanically mixed* and *not chemically combined* is shown by several facts. In the first place, the *proportions* of these two gases are found to vary slightly. The quantity of oxygen usually varies from about 20·9 to 21 volumes per 100, sometimes falling (in towns) to 20·82, and rarely (in tropical countries) to 20·3, and we have seen that such variations do not occur in the composition of true compounds. Again, if we mix in a bell jar 79 volumes of N with 21 of O, no elevation of temperature occurs (as is the case when chemical combination takes place), and yet an "air" is formed identical in properties with that of the atmosphere. Moreover, the *properties* of air are just such as we should expect from a mixture of oxygen and nitrogen. For instance, we should expect that the air dissolved in water should contain more oxygen than usual (since oxygen is rather more soluble in water than nitrogen is), and this we find to be the case, air removed from solution in water containing 34·4 volumes of oxygen per cent., a number agreeing with the calculated one. The principal causes contributing to the great *uni-*

formity in the proportions of oxygen and nitrogen in different parts of the atmosphere (notwithstanding their different relative densities, which are as 8 to 7), are the molecular processes of diffusion (p. 62) and the more perceptible motion of winds (p. 110).

Besides O and N there are other gases contained in the air. CARBONIC ACID GAS is supplied by burning bodies, the breathing of animals, the decay of animal and vegetable substances, and also by volcanoes. Its average amount in country air is about 4 parts in 10,000 vols. of air. If there were not means by which this gas is used up, it would accumulate in the air in such quantities that animal life would become extinct. It is, however, removed by the action of plants. OZONE, a condensed form of oxygen, possessing great chemical activity, is most frequently detected on rainy days and during great atmospheric disturbances. It seems to be mainly produced by atmospheric electricity. AMMONIA AND OTHER COMPOUNDS OF NITROGEN occur only in very small quantities, but are important as supplying food material for plants. AQUEOUS VAPOUR is raised into the air by evaporation from every exposed surface of water. The amount of evaporation depends principally upon the temperature (the greatest amount occurring from the great oceans in the tropics), and upon the quantity of vapour already present in the air, since a liquid will go on evaporating only until the pressure of its vapour reaches a certain value depending upon the temperature. When the amount of vapour in the air is the greatest that can exist without increase of temperature, the air is said to be *saturated*, and the temperature of saturation is called the **dew point.** If the air be still, it soon becomes saturated, but winds cause a constant renewal of unsaturated air, and hence increase the amount of evaporation. The determination of the dew point may be made by means of instruments known as **hygrometers**, or by wet and dry bulb thermometers, consisting of two thermometers, one of which has its bulb kept wet by being surrounded with muslin or lamp cotton, one end of which dips into water (Fig. 35). The mercury in the thermometer sinks, owing to evaporation of the water, the amount of fall increasing with the rapidity of evaporation, which depends upon the amount of moisture in the air. The difference of the readings of the two thermometers thus enables us, by means of empirical formulæ, to determine the hygrometric state of the air at any given time and place. The ratio of the amount of vapour actually present to the whole possible amount at the temperature it possesses is termed the *relative humidity* of the air. When air is cooled, condensation begins as soon as the dew point is reached. The local condensation upon surfaces cooled by radiation constitutes **dew** (or when the temperature is below freezing point, *hoar frost).* The formation of dew is favoured by circumstances which promote radiation, such as a clear sky and the presence of good radiators. Hence more dew is deposited upon grass than upon stones, the grass being a better radiator and also a worse conductor, so that it loses heat more rapidly and receives less by conduction from the earth to make up for the loss. A more general condensation constitutes **fog** or **mist**, which consists of very minute drops of water just like the so-called cloud of "steam" issuing from a kettle spout. According to the experiments of Mr. John Aitkin, this condensation is promoted by the presence of

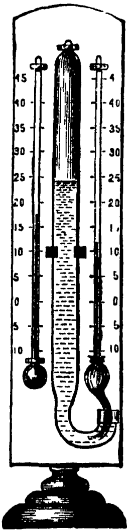

Fig. 35

DUST in the air, the dust particles serving as nuclei round which condensation can take place. Mr. Aitkin has shown that in a single cubic inch of air there are often many millions of dust motes.[1] Some of these particles are mineral substances such as sea salt, others are of organic origin.

Clouds are elevated mists, and may be formed by the chilling produced in an ascending current of air by the act of *expansion* (just as a cloud is formed in the receiver of an air pump by rapid exhaustion of the air), or by the cooling due to actual *contact*, when a warm wind blows against the side of a cold mountain; or, again, they may arise from the mingling of currents of saturated air at different temperatures, since the greatest pressure which aqueous vapour can exert at the mean of two temperatures is less than the mean of the two vapour pressures at those temperatures, and, consequently, a certain amount of condensation must take place. When the drops of water in a cloud or mist unite to form larger drops, we have **rain** produced. **Hail** is frozen rain, and **snow** consists of minute crystals of ice formed when a cloud exists at a temperature below 0° C.

4. **Distribution of Rainfall.**—The amount of rainfall in any given place and time is measured by means of the *rain gauge*, consisting of a metal cylinder to receive the rain, which is caught through a funnel, so as to prevent loss by evaporation. It is expressed by stating the depth (in inches) of water which would be formed, if it were to remain accumulated (say for a year) on a level surface where it fell. One inch of rain gives about 100 tons of water per acre. The most important general facts with regard to the distribution of rainfall (sometimes called the *laws of rainfall*) are that: (i.) *The average rainfall for the year decreases from the tropics to the poles.* This is owing to the greater evaporation

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[1] Trans. Roy. Soc. Edin., vol. xxx., part i.; and vol. xxxv., part i.

in tropical regions. The heaviest rainfall of the oceanic areas is in the belt between the N.E. and S.E. trades. (ii.) *The average rainfall decreases as we pass from the coast lines to the interiors of continents;* the aqueous vapour brought by the winds which have traversed the ocean being usually condensed near the coast, especially when hilly regions oppose their course. (iii.) *The average rainfall increases* (within certain limits) *in ascending from sea level,* since, as we have seen, air in ascending expands and becomes thereby chilled.

The key to the distribution of the rainfall over the BRITISH ISLES is to be found in the prevalent westerly winds which have crossed a great extent of ocean, and to the mountainous character of much of the western part of Britain, which gives the requisite ascensional current needed to produce copious precipitation. Thus, in the Lake District and North Wales, the average for the year is about 75 inches, and over a large part of the Scottish Highlands exceeds 80 inches, while to the east on the lee-side of the great mountain ranges it does not exceed 30 inches, the air getting drier as it descends to lower levels.

Special geographical conditions may give rise (1) to regions of *excessive rainfall,* as in the case of the Khasi hills, 100 miles N.E. of Calcutta, where the annual fall is between 500 and 600 inches; this great precipitation, which occurs in a few months, being due to the warm moist S.W. monsoon from the Indian Ocean being suddenly deflected upwards by the mountain range which rises abruptly from the lowlands to the south; and (2) to practically *rainless* districts (like the Sahara, Desert of Gobi, and coast of Peru), which are generally elevated plateaus, exposed to dry winds, and sheltered by mountain ranges from moisture-laden air.

5. **How the Air is Warmed.**—The main source of atmospheric heat is the sun; hence we should be inclined to

expect that the higher regions of the atmosphere would be the warmest as being nearer the sun. As a matter of fact we know that in general the higher we ascend the colder it becomes, the diminution of temperature being approximately 1° for 270 feet of ascent. The reason is that the luminous rays of the sun pass through the air without being very much absorbed, and strike the earth, which absorbs them and becomes heated. Now a hot body loses heat both by *conduction* and by *radiation* (the nature of which will be further considered in Chapter IV.), and it is found that the non-luminous radiation, or *dark heat* from the comparatively cool earth, will not pass through the atmosphere so readily as the luminous radiation of the sun (just as, for instance, in the case of luminous rays, a blue glass will transmit blue light but will almost entirely arrest the passage of red light). Hence these dark heat rays are mostly absorbed by the lower layers of the atmosphere. Moreover, the air resting upon the earth becomes warmed by contact. Thus it will be seen that the higher air is colder because it is really further from the principal direct source of heat (the earth), and it is in addition so situated as to part with heat more readily by radiation into the cold of space beyond the limits of the atmosphere. Water is a very good absorber of radiant heat; hence cloud forms a sort of blanket to the earth, greatly checking the loss of heat due to nocturnal radiation, which may be regarded as the principal source of atmospheric *cold*. In the winter, when the sun is low and the days short (so that loss of heat by radiation from the earth becomes more powerful than gain of heat by radiation from the sun), rainy weather is warm because the clouds prevent great loss of heat by radiation, and clear weather is cold because then radiation goes on comparatively unchecked, whereas in the summer, when the sun shines nearly vertically and the nights are short, clear weather is hot, because we get more heat from the sun when there is no cloud, and rainy weather is cold because the clouds cut off much of the sun's heat. Winds also greatly affect the temperature of the air, especially in winter. If the earth were entirely covered with water, or consisted of flat land only, the **climate** of any place (*i.e.*, the average condition of the atmosphere with regard to heat or moisture) would be determined by its *latitude*; but, as we have already seen, the difference in the specific heats and radiating powers of the land and water areas has a very important effect on climate, continental climates being always extreme (hot in summer, cold in winter), and oceanic and insular climates equable and mild. The effect of ocean currents is also marked, as in the case of the Gulf Stream, the heated waters of which greatly modify the climate of N.W. Europe, so that, for example, London does not experience the excessive heat and cold of places in the same latitude in Asia or North America.

6. **The Movements of the Air.**—Any alterations in the atmospheric pressure at different places at the same level produce movements of the air or **winds** blowing from the regions of high pressure (where there is a *surplus* of air) to the regions of low pressure (where there is a *deficit* of air). Such alterations of pressure arise mainly from *differences of temperature*, and from *differences of humidity*. The air in contact with any heated portion of the earth's surface will be raised in temperature and will expand; and similarly a diffusion of aqueous vapour in the air, due to increased evaporation, will cause it to expand, because it supports a portion of the pressure to which the air was subject. At the **thermal equator**, or zone of greatest heat (which, owing to the greater amount of land in the northern hemisphere,

lies to the north of the geographical equator), the air is heated, expands and rises; there is also much evaporation. The column of air and vapour ascends to a great height, and then, sinking as it parts with its heat and moisture, flows in gentle curves towards the poles, while air flows in along the surface of the earth from the sub-tropical regions to supply its place. Since, however, the rotation of the earth affects the direction of bodies moving on its surface so as to deflect them to the right in the northern and to the left in the southern hemisphere, this indraught towards the equator, which would otherwise flow direct from the north and south is deflected towards the west. Hence arise the **trade winds** which blow constantly from the N.E. in the northern hemisphere and from the S.E. in the southern hemisphere, as shown in Fig. 36. The meeting region of N.E. and S.E. trade winds constitutes the rainy equatorial *zone of calms* or doldrums, which, following the sun, shifts northwards in the northern summer and southwards in the southern summer, the limits of the trade wind areas being correspondingly altered. The **counter trade winds** are less constant south-westerly and north-westerly winds, due to the sinking in the temperate zone of the upper warm current flowing from the equatorial regions. They are more constant in the southern hemisphere, blowing in the latitudes (between 40° and 50°) known as the "Roaring Forties." Besides these more or less constant systems of winds, there are various systems of

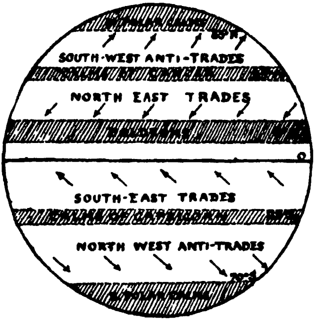

Fig. 36.

periodic winds, such as the land and sea breezes (most marked in tropical countries), due to the fact that the land is hotter than the sea by day and cooler by night, thus causing the air over the land to rise in the daytime and cool air to flow in from the sea to supply its place, while at night the cooled air over the land becomes heavier and flows seaward. The S.W. **monsoons** of the Indian Ocean, blowing from April to October, are due to a *reversal* of the N.E. trade winds (which blow during the rest of the year and constitute the so-called N.E. monsoons), owing to the land masses of S. Asia being hotter during the summer than the equatorial parts of that ocean: they are thus like sea-breezes on a large scale.

7. **Weather Charts and Storm Warnings.**—In order to trace out the varying local eddies and other movements of the atmosphere, we make use of *synoptic charts*, in which the distribution of pressure is graphically represented by means of isobaric lines, or **isobars.** These are lines drawn through all places at which the barometer readings are the same at the same time. (Since, however, a fraction of the change in height of the mercury in the barometer may be due to expansion of the mercury owing to change of temperature, and since the reading of a barometer depends upon its height above the sea, corrections have to be applied to the observed readings, in order to be able to compensate for the varying conditions, hence the readings are said to be "corrected to 32° F., and reduced to sea level.")

The isobars are usually found to form certain *definite shapes*, of which the most important are closed curves round the areas of high or low pressure. When the barometer reading is lowest in the centre, we have a cyclonic, and when the highest reading is at the centre, an anti-cyclonic distribution of pressure. Observation shows that the

WINDS follow roughly the course of the isobars, the direction of rotation being (in the northern hemisphere) clockwise in anti-cyclonic, and anti-clockwise in cyclonic systems, this difference being doubtless due to the effects of the rotation of the earth causing a deflection to the right, as shown in Figs. 37 and 38, where the dotted arrows show winds blowing directly toward the low-pressure, and away from the high-pressure areas, while the other arrows show the right-handed deflection due to the earth's rotation. The direction of the wind in the northern hemisphere is expressed by Buys Ballot's rule—"Stand with your back to the wind, and the barometer will be lower on your left hand than on your right."

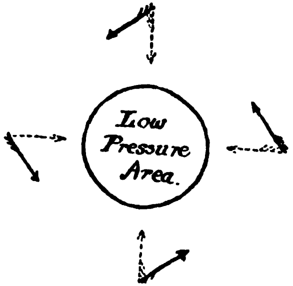

Fig. 37.

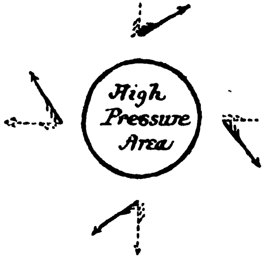

Fig. 38.

The VELOCITY OF THE WIND is found to be proportional to the *closeness* of the isobars, which are generally drawn to represent successive differences of barometric readings of $\frac{2}{10}$ of inch (or about 5 mm.). It will be easily seen that lines at right angles to the isobars represent the directions in which the variation of pressure is the greatest. This variation is known as the **barometric gradient**, and is measured in terms of $\frac{1}{100}$ in. for 15 nautical (17 statute) miles. A gradient of 3 corresponds to a fresh breeze, a gradient of 6 to a strong gale.

The character of the WEATHER (cloud, rain, fog, etc.) is related to the *shape* of the isobars, some shapes enclosing areas of fine, and others of stormy weather. The main characteristics of *cyclonic weather* are as follows:—In the front of the cyclonic area the air is warm, moist, and muggy, and stratified forms of cloud prevail; in the rear the air is cool and dry, with a bright sky, and predominance of cumulus cloud; near the centre there is rain, due, no doubt, to the ascensional current. The storms of the temperate zone are usually cyclonic in character, and the whole system is usually found to travel E. or N.E. (its course being probably largely determined by the general larger system of winds which prevail) at an average rate, in Europe, of about 17 miles an hour. Hence the possibility of *forecasting* the weather. Since, however, most of our storms come from the W., it will be seen that Great Britain is unfavourably situated in the matter of storm warnings, and it is not therefore surprising that the average success of weather forecasts is greater (about 90 per cent.) in America than in this country.

Fig. 39 is a copy (omitting some of the details) of the *weather chart* for Sunday, February 26, 1893 (6 p.m.), as given in the *Times* newspaper of the following day. The dotted lines are the isobars, the values being marked (in inches) at the end. The arrows fly with the wind, the force of which is shown by the number of barbs and feathers. The asterisks denote the positions of the various meteorological stations. The crossed line shows the apparent movement of the centre of disturbance; thus, at 6 p.m. on Saturday, February 25th, the centre of the depression was at A; by the following morning (8 a.m.) it had advanced to

B, and the barometer had fallen to about 28·8 in. in South Wales, Devon, and Cornwall, strong squally winds and gales from the S. and S.E. being felt over the southern parts of the kingdom. As the cyclone system advanced during the 26th towards the N.E., it became deeper, so that at 6 p.m., as shown on the chart, the barometer was as low as 28·6 in. over the north of England, while the wind in the south had shifted, and was blowing from the N. and N.W. During the following day the centre of the depression moved steadily along the North Sea coast towards the Shetlands, and the wind in Scotland backed to N.W. and W. “Heavy snowstorms were experienced over nearly the whole of North Britain, with severe gales on the east coasts, and a very high sea.”

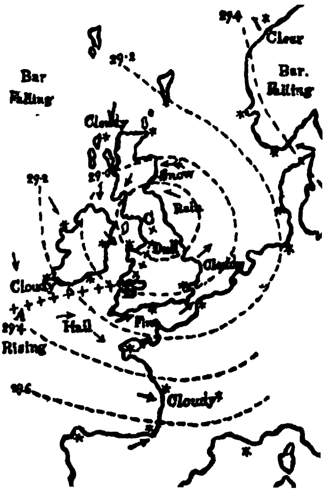

Fig. 39.

The reader will probably obtain a clearer idea of the successive changes of wind and weather, and of their relations to the passage of the cyclonic system, by copying the dotted lines and arrows upon a piece of tracing paper, and placing the centre of the inner circle successively over the points marked by the crosses from A to C. It will then be easily seen how it is that—since the wind is blowing in a spiral form—a storm may be coming up from the west, and yet the wind (in front of it) may be blowing from the east.

A cyclone may be only 50 miles across, or it may be 2000. Whirlwinds and the still more violent tornadoes on land, and waterspouts at sea, differ from cyclones in that their height is enormously greater than their width. They may be only two or three feet in diameter. Their nature and origin is not fully understood.

The primary feature of *anti-cyclonic weather* is *calm*; the air in the centre is descending, and is therefore dry, and since the whole system is usually much more stationary than a cyclone, an anti-cyclonic distribution of pressure generally indicates settled fine weather, cold in winter, hot in summer.

References.—*Air and Water*, by Prof. V. Lewes (in this series).
Weather, by Hon. R. Abercromby (International Science Series).
Popular Treatise on the Winds, by W. Ferrel (Macmillan).
Meteorology, by H. V. Dickson (in this series).

Section IV.—The Waters of the Earth.

1. **Composition of Pure Water.**—We have already seen that water is not an *element* but a compound substance, and that it is formed by the burning of hydrogen in air. The discovery of the composition of water was made in 1784, by Cavendish, who showed that if two volumes of hydrogen were mixed with one volume of oxygen, and the mixture exploded by an electric spark in a closed vessel, the gases wholly disappeared, leaving water as the only product of their union. He further showed that the weight of the water produced was the same as that of the gases which combined. It does not appear from his writings, however, that Cavendish had clear views as to the fact that water is

really a compound of the two elementary substances, oxygen and hydrogen.

Nicholson and Carlisle, in 1800, showed that water is separated into its constituents by the passage of an electric current. (*See* p. 48.) It was subsequently found that when water was thus submitted to *electrolysis* in the open air in glass vessels, traces of *alkali* and of *acid* were produced, but Davy proved that these were derived from substances contained in the glass and air respectively, chemically pure water yielding gaseous substances only.

The constituents of water being gases, we may state its *quantitative* composition either by *volume* or by *weight.* In the electrolysis of water it is found (after correcting for errors due to the greater solubility of oxygen in water, and to its partial condensation into ozone) that the volume of hydrogen is exactly double that of oxygen. We therefore conclude that water is made up of *one volume of oxygen combined with two volumes of hydrogen.* This is confirmed by *synthetic* (putting together) experiments like those of Cavendish. It must be observed, however, that the volume of water produced is only about $\frac{1}{2500}$ of the volume of the mixed gases.

The experiments of Dumas and others have shown that *by weight* nine parts of water consist of one part of hydrogen united to eight parts of oxygen (very nearly).

That water is a *pure compound substance* and not a *mixture*, is shown by the following facts:—(i.) Its constituents can be separated only by means of electricity, or of a very high temperature (1500°—2000° C.), or by the *chemical* action of certain substances upon it; (ii.) the *proportions* of these constituents are perfectly fixed and definite; (iii.) the *properties* of water are very different from those of its constituents; (iv.) when oxygen and hydrogen unite to form water a large amount of *heat* is produced, and a great contraction of volume occurs.

2. **Composition of Rain Water.**—The water which occurs in nature is not a pure substance; most of it has a very turbid appearance, arising from the presence of matter carried mechanically in suspension. This suspended matter may be removed either by decantation, *i.e.*, allowing the material to gradually sink to the bottom of the vessel containing the water, and then carefully pouring off the clear liquid above, or by filtration through some porous material such as (on a large scale) a bed of sand and (on a small scale) a piece of porous paper folded into a funnel. But, besides this visible suspended material, the various natural waters contain dissolved impurities which cannot be removed by filtering. Water is the most general solvent known, and comparatively few solid substances, except some of the pure metals, are able to wholly withstand its solvent action, even glass being dissolved to some extent by long contact with water.

In order to obtain water free from these dissolved impurities we must have recourse to the process of **distillation**, which consists in converting the water into vapour by the aid of heat, and recondensing the vapour into the liquid form in a separate vessel. On a small scale the arrangement shown in Fig. 40 may be used.

The water thus condensed contains only a certain amount of dissolved gases, all the non-volatile impurities having been left behind in the first vessel.

Such a process of distillation is continually going on in nature; water is constantly being evaporated into the air from the surface of sea, river, lake, and pond; and, as we have already seen, when the damp air gets chilled, this water is deposited in the form of dew or rain. *Rain-water* *is then a kind of naturally distilled water*, and is the purest kind of natural water, because it can contain only gases and such solid substances as it meets during its fall through the atmosphere. One gallon of rain-water will generally furnish about four cubic inches of nitrogen, two of oxygen, and one of carbonic acid gas. In towns the rain-water is often distinctly acid, and its oily and sooty taste renders it quite unfit for drinking.

3. **Spring and River Water.**—As soon as the rain water reaches the ground it begins to dissolve any soluble material with which it comes into contact; whether it dissolves much or little will depend upon the kind of rock or soil through which it passes, but in all cases it dissolves something; hence *spring water*, or water that has passed through more or less soil and rock, is more impure (*i.e.*, has a greater amount of substances dissolved in it) than rain water. Of the mineral substances found dissolved in ordinary spring or well water, the most important are COMMON SALT, and certain compounds of LIME, whose presence may be detected by simple chemical tests. It is to the presence of the lime compounds that the **hardness** of most spring water is mainly due. By a hard water we mean simply a water

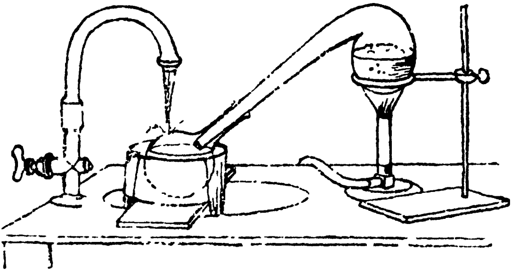

Fig. 40

which curdles soap and does not at once form a lather with it. This hardness is of two kinds—*temporary* and *permanent.* The former is usually due to the presence of CARBONATE OF LIME (chalk or limestone) in solution. Chalk is practically insoluble in pure water, but it dissolves to a very considerable extent in water containing carbonic acid in solution. Now, rain water contains, as we have seen, some carbonic acid gas dissolved from the atmosphere, and in the surface soil it usually meets with a further supply of this substance. It is therefore able to dissolve small portions of any rock or soil containing carbonate of lime; thus becoming hard. If this hard water be boiled for a short time the carbonic acid gas is driven off, and the chalk, being insoluble in the water freed from carbonic acid, is precipitated, becoming a suspended instead of a dissolved impurity, and as such it can be removed by decantation or filtration. A water whose hardness is due to the presence of carbonate of lime dissolved in it can therefore be softened by boiling: hence the term temporary hardness. (In some cases, temporary hardness is due to carbonate of magnesia instead of carbonate of lime.) The "fur" deposited in kettles, and the solid crust formed in boilers, is usually largely composed of carbonate of lime, thus removed from solution by the process of boiling. Temporarily hard waters may also be softened by adding to them a suitable quantity of lime, in which case the lime (calcium oxide) combines with the carbonic acid gas to form chalk (as expressed by the equation $CaO + CO_2 = CaCO_3$), but in so doing the carbonic acid has to give up the chalk which was originally held in solution, and so both the original chalk and the freshly formed chalk are removed from solution as a precipitate, which ultimately sinks to the bottom of the containing vessel. SULPHATE OF LIME, or gypsum, is soluble in water, even if no carbonic acid be present. Water which is thus made hard cannot be softened by boiling or by adding lime, and is therefore called permanently hard. Permanently hard waters may be softened by the addition of carbonate of soda, the chemical action being that described on page 86.

When hard waters are used for washing purposes, the lime or magnesia compounds decompose the soap, forming insoluble curdy compounds, and great waste of soap results. The hardness of water is often expressed in degrees which indicate the number of grains of carbonate of lime (or its equivalent) in each gallon of water.

Mineral waters are simply spring waters containing so large a quantity of some ingredient as to have a decided taste or medicinal action. Those containing salts of iron in solution (as at Spa), are termed *Chalybeate* waters. Others containing various salts such as magnesium sulphate (Epsom salts), or sodium sulphate (Glauber's salts), are classed as *saline* waters.

River water, consisting essentially of spring water largely mixed with surface rain water, is usually softer than spring water, except where it has received sewage and refuse water from towns. The following table, taken from Professor V. Lewes's "Air and Water," shows the results of the analysis of some natural waters, the numbers showing the amount (in grains) of each substance in one gallon of the water.

	Spring.	River.	Sea.
Calcic Carbonate	16·30	10·80	3·32
Calcic Sulphate	5·37	3·00	93·21
Magnesic Carbonate	0·00	1·25	trace
Magnesic Chloride	0·00	0·00	220·55
Magnesic Sulphate	0·93	0·00	144·62
Sodic Chloride	2·64	1·80	1850·74
Silica, Alumina, etc	0·23	0·[illegible]7	trace

Just as dissolved carbonate of lime is deposited in the solid form, as "fur" in kettles, so on a larger scale in nature this substance may be deposited from calcareous waters in the form of the **stalactites** and **stalagmites** so frequently seen in limestone caverns. Each drop of water which percolates through the cavern roof, charged with its load of carbonate of lime, deposits a tiny speck of solid, as a little of the water and carbonic acid evaporate; thus in time a pendent icicle-like mass of this material grows down, often to be met by the upward-growing stalagmite due to a similar deposition from the countless drops which reach the floor. The grotto of Han in Belgium, the caves of Adelsberg, in Carniola, the Fish River caves near Sydney, in Australia, and the caverns of Luray in Virginia, are some of those which exhibit the most remarkable examples of these deposits. Objects, such as birds' nests, are often placed beneath the drip of calcareous waters, and become encrusted with a coating of carbonate of lime. They are popularly but erroneously said to be "petrified," or converted into stone. A more continuous mass of deposited carbonate of lime, thrown down by larger streams, constitutes the material known as **travertine** or **tufa.**

4. **Waters of Salt Lakes.**—The waters of such lakes as the great Canadian lakes, which are practically merely outspread rivers, have much the same composition, but there are other lakes, such as the Dead Sea, that have no lower outlet, lakes that keep their normal level by evaporating as much water as they receive from rain and rivers, and the water of these lakes is always salt. It is popularly supposed that all such salt lakes have been portions of the sea. This is doubtless the case with the Caspian, which appears to be simply a portion of the Mediterranean cut off by the gradual elevation of the intervening country. The Great Salt Lake of Utah, on the other hand, is not a portion of the sea, but the remnant of a once much larger fresh water

lake system. The present lake is about 80 miles long, and 20 to 32 miles broad; it is partly surrounded by mountains, along the sides of which well marked terraces indicate former levels of the water: the highest of these beach lines is about 940 feet above the present water level, so that, at one time the lake was 300 miles long and 180 miles broad. Its waters were then undoubtedly fresh, for it had an out-let to the North, and in its stratified deposits the remains of fresh water shells have been found. To this extinct sheet of water Mr. Gilbert has given the name of Lake Bonneville. Owing to some change in the climate the lake began to shrink, and when it had sunk below the level of the outlet, it began to get more and more saline because it was constantly receiving river waters containing common salt, chalk and other substances in solution, while its only outlet was by evaporation; the water which flowed in was hard, the water which came out (as vapour) was soft. So strongly saline is the water of the present Great Salt Lake that a swimmer floats in spite of himself, and "the under surfaces of the wooden steps leading into the water from the bathing places, are hung with short stalactites of salt from the evaporation of the drip of the emergent bathers." The following table shows approximately the percentage composition of the water of this lake, and of ordinary sea water.

	Great Salt Lake.	Ordinary Sea Water
Water	85·006	96·470
Sodium Chloride	11·862	2·700
Magnesium ,,	1·490	0·360
Potassium ,,		0·070
Calcium Sulphate	0·085	0·140
Magnesium ,,		0·230
Potassium ,,	0·536	
Sodium ,,	0·932	
Calcium Carbonate,		0·003
Bromides, Iodides, Silicate,	0·086 (excess chlorine).	0·027

It will be seen that the water of the Great Salt Lake contains no carbonate of lime, but a great deal of common salt. What then becomes of the carbonate of lime carried into it by rivers? It is apparently all precipitated. Further to the west was another great fresh water lake (Lake Lahontan of Clarence King), and its ancient terraces are abundantly cemented with such deposited carbonate of lime; several square miles of calcareous tufa 20 to 60 and even 120 feet thick being now found on the site of its ancient waters.

5. **The Composition of Sea Water.**—It will be seen from what we have learned as to the composition of terrestrial waters, that every river carries down each year to the sea an enormous quantity of mineral matter in solution. When the water evaporates from the surface of the sea, this dissolved matter is left behind, and it must therefore tend to accumulate in the oceanic waters, just as it has done in those of the Great Salt Lake, unless there are means by which it gets removed from solution. Now, the above analysis of sea water shows that although the rivers are carrying into the ocean great quantities of lime compounds, these are not the most important of the mineral constituents of sea water. The reason of this apparent anomaly is simple: many marine organisms, such as the coral polype, globigerina, and "shell fish," extract the dissolved lime compounds to build up their calcareous shells or skeletons, and owing to this action (which, as we shall see later on, has resulted in the removal of immense quantities of carbonate of lime from the sea to form our chalk and limestone rocks), sea water contains comparatively little dissolved chalk. The common salt carried into the ocean by the rivers is not thus removed; its indefinite accumulation in sea water is, however, prevented by other processes. From time to

time a portion of the oceanic water gets cut off from communication with the open sea and begins to dry up by evaporation. Now, when sea water is evaporated, its dissolved salts are left behind in the solid form ; as soon as one-third of the water is evaporated off, it begins to deposit its sulphate of lime, this substance being much less soluble than common salt, which is not thrown down until 93 per cent. of the water has been evaporated, hence it is that deposits of rock salt are usually associated with, and rest upon deposits of gypsum. The Caspian Sea is still too fresh to deposit its salts except in the shallow pools and bays where evaporation proceeds rapidly. The Dead Sea has already deposited its gypsum and much of its common salt, so that it now contains much more of the very soluble chloride of magnesium than it does of chloride of sodium : on its southern shore is a ridge of rock salt seven miles long, and 300 feet high, known as the Ridge of Sodom. Our English salt deposits of Worcestershire and Cheshire were similarly formed in a salt lake which probably originated like the Caspian in the cutting off of a portion of the main ocean by subterranean elevation. The Triassic rocks of Britain exhibit in detail the characteristics of the deposits of modern salt lakes.

It will be seen that, given a fresh water sea, the effects of the actions now in progress would be to convert it into a salt water sea, just as on a smaller scale the fresh water Lake Bonneville has become the Great Salt Lake. In all probability, however, the sea never was fresh (the first formed hot ocean probably containing more dissolved material than the present seas), and it is impossible to say how much of the saltness of modern sea water is original.

6. **The Great Oceans.**—The waters of the sea cover about $\frac{5}{7}$ of the total surface of the earth. The area of the

Pacific Ocean is nearly ½, and of the Atlantic nearly ¼ of the total sea area. Our knowledge of oceanography has been much enlarged by the researches of the *Challenger* (1872-1876), and other deep-sea exploring expeditions. The DEPTH of the ocean varies from 1,000 to 30,000 feet (about 5½ miles), the average being probably about 12,600 feet. The maximum height of the land above the surface of the sea is also about 5½ miles, but the average height of the land is estimated by Dr. John Murray to be only about 2,200 feet above "*sea level.*" The level of the sea varies not only on account of tides and waves, but also because of the water's yielding to the attraction of elevated masses of land, so that there is much uncertainty about the relative levels of distant places. The heights on our survey maps are measured from the level of *meantide at Liverpool.*

The SEA-FLOOR appears to be smoother than the land surfaces. It sinks, generally rapidly, from the coast lines down to a depth of 2, 3, or more miles, and continues as an undulating plain, rising occasionally into broad, submarine ridges or plateaux. The Atlantic basin, for example, is divided into three distinct troughs or hollows (whose mean depth is over 2,500 fathoms, or 15,000 feet) by a ridge extending along the middle through its whole length, and joined to the northern coasts of S. America. This ridge is known as the *Dolphin Ridge* in the N. Atlantic and as the *Challenger Ridge* in the S. Atlantic, the two portions being joined by the *Connecting Ridge;* its average depth is about 1,500 fathoms (9,000 feet), and from it rise the volcanic islands of Tristan, Ascension, St. Paul, and the Azores. These submarine ridges have an important influence on the distribution of TEMPERATURE over the ocean floor. Except in the iceberg region of the Antarctic circle the water is always warmest at the surface, where, near the equator, it reaches 80° F. It cools rapidly for the first few hundred fathoms, and then slowly down to the bottom, or to the level of the submarine ridges which cut off the supply of colder water. In the temperate parts of the N. Atlantic the water is above 40° F. to a depth of one mile or more; in the tropical and south temperate regions a temperature of 40° F. is reached at the depth of about ½ a mile; while as we approach polar regions the temperature of 40° is met with at the surface. The bottom temperature in the E. and N.W. depressions is about 35°, but in the S.W. basin, where there is a free communication with the Antarctic waters, it sinks to 31° F., or below the freezing point of fresh water. The low temperature of this deeper water is evidently produced by cold under-currents flowing from the polar region. These under-currents cannot enter the other basins on account of the intervening ridges. Similarly in inland seas, such as the Mediterranean, the minimum temperature is reached within a few hundred fathoms below the surface. In the Mediterranean the temperature never falls below 50° F., the Strait of Gibraltar having a depth of less than 200 fathoms, and admitting no water colder than 55°. The bottom temperature of the Atlantic outside the straits is 37°.

The MOVEMENTS OF THE OCEAN may be classed as (i.) *Tides*, (ii.) *Waves*, (iii.) *Currents*. The causes of the tides have already been briefly noticed in Chapter II. Section 3. **Waves** are produced by the action of the wind, just as upon a small scale such movements may be produced by blowing upon the surface of water in a basin. On studying such waves we find that while the waves travel horizontally onwards the actual motion of individual water particles is only an up and down movement, for a floating cork or chip of wood is merely raised or depressed and not perceptibly shifted horizontally as the wave passes. In each wave we distinguish crests and troughs; the *length* of a wave is the distance from one crest to the next. The largest waves of the sea are about 50 feet high from trough to crest, their length being sometimes half a mile, and they travel at the rate of about 80 miles an hour. Smaller waves travel less rapidly. The movements of the oceanic waters known as **currents** appear to be due to several causes. By some authors they have been attributed chiefly to the impulse of the prevailing winds, and Mr. A. W. Clayden has constructed a model of the Atlantic, in which a system of miniature currents corresponding to those of the real ocean is produced by air currents blown from a number of tubes so as to imitate the movements of the actual winds. A reference to any good physical atlas will show that there is a fairly close correspondence between the directions of the chief winds and surface currents, while it seems clear that such currents as those of the Indian Ocean, which change twice a year with the monsoons, must be mainly wind-formed. Other observers, however, give more prominence to the effects of differences of *temperature* and *saltness* in the different parts of the sea, which must cause disturbances of equilibrium tending to set up movements of the water. Whatever the relative importance of these and other causes, the actual movements are modified by (i.) *the rotation of the earth*, which, as we have seen (p. 45) tends to deflect bodies moving on its surface, and (ii.) by the different forms of *coast lines* and irregularities of the sea-floor, which tend to produce local variations. The *general* movement of the surface waters forms a right-handed whirl or vortex in the N. Atlantic and in the N. Pacific, and a left-handed whirl in the southern parts of each ocean. The western part of the N. Atlantic whirl constitutes the *gulf stream*, which is a river of warm salt water about 50 miles wide, flowing at the rate of about 5 miles an hour, from the Gulf of Mexico through the Strait of Florida and gradually spreading out fan-like, as it travels with diminishing velocity eastward across the Atlantic. Its effects upon the climate of W. Europe have already been noticed (p. 110). Professor Haughton calculates that the Gulf Stream carries into the north temperate zone one-twelfth part of the heat received by the torrid zone from the sun.

In addition to these more *constant* surface currents, the rise and fall of the tides produce *periodical* currents along the coast lines. In the case of such estuaries as those of the Severn and the Hooghly, the gradual narrowing of the channel causes the inflowing waters to be heaped up in a sort of ridge or wall termed a *bore*.

References.—Prof. V. Lewes, *Air and Water* (Methuen). For salt lakes, Geikie's *Text Book of Geology* (Macmillan). And for oceanography, *Physical Geography Primer*, by Prof. P. M. Duncan (Ward, Lock & Co.); Prof. Haughton's *Lectures on Physical Geography* (Longman); Mill's *Realm of Nature* (Murray), and works there cited.

CHAPTER IV.

WORK AND ENERGY.

Section I.—The Principle of the Conservation of Energy.

1. **Meaning of the Terms Work and Energy.**—In the last chapter the principle known as that of the Conservation of Matter has been illustrated and explained. We have now to consider a second great principle in Science, that of the Conservation (or Indestructibility) of Energy. At the outset of our inquiry it will be necessary to have a clear idea of what is meant by the word "energy" as used in physical science. When we speak of a man of great energy, we imply that the person thus spoken of is capable of doing a large amount of work. Similarly in applying the term to an inorganic body or system of bodies, we define **energy** as the *capacity for doing work* or overcoming resistance of any kind, and the amount of energy is measured by the amount of work which the system can perform. We get some idea of different amounts of work from the sensation of fatigue which usually succeeds great muscular exertion. But our sensations alone will not give us a very definite measure of work, and, therefore, it is necessary in Physics to have a more precise method of measurement. If we consider the case of a clock which is put in motion by a weight sinking to the ground, it is quite clear that this weight in falling does work in overcoming the resistances of the air, and the friction of the various parts of the works of the clock which

would otherwise soon cause the movements to stop. When the weight reaches the ground, it has lost this power of doing work, which, however, it regains when we wind the clock up by the power of the arm. In so doing, we do a certain amount of work against the resistance of gravity which tends to pull the weight to the ground, and the weight is again in a position to put the clock in motion. Now, suppose we have such a clock in which a 1 lb. weight falls through a distance of 10 feet, and in so doing keeps the clock going for one whole day of 24 hours: we have here a certain definite piece of work performed, and it is evident that if the length of the string be doubled so that the weight falls through 20 feet instead of 10, the clock will go for two whole days and we shall have twice as much work done, the same set of resistances being overcome in the second day as on the first. We conclude, therefore, that the weight remaining the same, the work done is proportional to the distance through which it falls, and that by doubling the distance we double the amount of work. If, further, we imagine that ten such clocks were made exactly alike, each driven for 24 hours by a 1 lb. weight falling through 10 feet, it is equally clear that (since each weight has to overcome the same resistances as the original one) we shall have ten times as much work done by these 10 lbs. falling through 10 feet, as was done by the 1 lb. weight falling through the same distance. Hence we see that, keeping the distance the same, the amount of work done increases directly as the weight. We may, therefore, in measuring the amount of work done by a falling weight, take the *product of the weight multiplied by the distance through which it falls as the measure of the work done.*

It will be seen from the illustration considered, that no work is done by the force of gravity, so long as a weight rests upon the ground. In order that work may be done, the weight must move through a certain distance.

A force then may be said to do work when it *moves its point of application in its own direction;* and the **unit of work** is defined as the amount of work done by a unit force in moving through a unit distance. The unit of work commonly adopted in this country is the *foot-pound.* This is the work done by a pound weight in falling through 1 foot. Since the *weight* of a pound varies slightly at different parts of the earth's surface, the foot-pound will have a corresponding difference in value. The C.G.S. unit of work is called an *erg.* (Gr. *ergon*—work); it is the work done by a dyne in moving through a distance of one centimetre in its own direction. If the point of application of a force is moved only in a direction at right angles to the direction in which the force acts, it will easily be seen that no work is done; thus work is done in lifting a weight through a certain vertical distance against the force of gravity which tends to pull it downwards, but no work is done against gravity in sliding the weight horizontally along a smooth level surface, though in practice a small amount of work has to be done in overcoming the resistance of friction.

It will be seen that the *time* taken to perform a certain piece of work does not enter into the definition of work as given above. The *rate* at which an agent can work is called its **power**, and is measured by the number of units of work which it can do in a unit of time. An agent which can perform 33,000 ft. lbs. of work in one minute, or 550 ft. lbs. in a second, is said to be of one-horse power.

2. **Function of a Machine.**—The principle of the conservation of energy has been thus stated by Maxwell:—"*The energy of a system is a quantity which can neither be increased nor diminished by any actions taking place between*

the parts of the system, though it may be transformed into any of the forms of which energy is susceptible."

Now, if we consider the action of any of the common *mechanical powers*, such as a lever, a wheel and axle, or a system of pulleys, it appears at first sight as if we had a distinct creation of energy. Let us suppose, for instance, that we have a large weight which it would require three men to lift without the aid of any mechanical contrivance. We know that by using a system of pulleys, such as are shown in Fig. 41, one man might lift the weight which, without this mechanical arrangement, would require the united efforts of three men. Here, then, it seems as if energy had been created by the machine. A further consideration shows, however, that in order to raise the weight through 1 foot the man must pull the end of the rope down through 3 feet (for it is evident that the length through which the free end of the cord is pulled has to be distributed through three ropes, each of which is therefore shortened by only $\frac{1}{3}$ of this length). Hence there is no real creation of energy; in fact, calling the pull on the string P (the power), and the weight raised W, we have, in such a system of pulleys (neglecting friction) :—

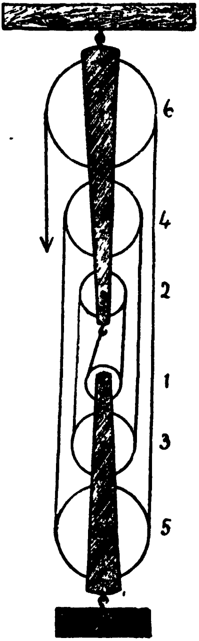

Fig. 41.

W × distance through which it ascends = P × distance through which it descends.

That is to say, the work done is the same in each case.

Similarly in any other mechanical arrangement, what we gain in one way we must lose in another; hence the workshop adage, "*What is gained in power is lost in speed.*"

The principle of the conservation of energy, in so far as it relates to the work done by a simple machine without friction, was really stated by Newton in his second interpretation of the third Law of Motion. Practically, however, we cannot neglect friction, and no machine really gives back the whole of the work spent upon it. In Newton's time it was thought that the work done against friction was absolutely lost or annihilated; we now know that it is converted into heat, and we shall see that heat is itself a form of energy.

3. **Heat a Form of Energy.**—We will begin by considering the case of a steam-engine, in which a piston is driven backwards and forwards by the steam, which, after each stroke, is condensed again into water. Now, it is evident that if no heat were lost by the way, the steam which is generated in the boiler would ultimately carry with it to the condenser the whole of the heat supplied to it by the boiler fires. In practice, of course, some heat must be lost by the way. But it has been found by a long series of experiments, conducted by M. Hirn of Colmar, that when an engine is at work the steam returns *much less heat to the condenser than can be accounted for by the ordinary sources of loss*, and that for every unit of heat which thus disappears, a certain *definite* quantity of mechanical work is performed. We have, therefore, in a steam engine a case of the *conversion of heat into work:* the heat has to pass out of existence as heat before it produces visible motion. On the other hand, whenever motion is stopped by friction, or by percussion, heat is produced. If a metal button be briskly rubbed on a wooden table it will very soon become

hot enough to set fire to a piece of phosphorus; when the break is put on, sparks are often seen to fly from the wheels of a railway train; when a cannon ball strikes an iron target a flash of light is sometimes observed; and among uncivilised people fire is usually kindled by the friction of two pieces of wood rubbed together. It will be noticed that in all these instances we have motion *arrested;* the moving body must be deprived of its motion if heat is to be produced. We have, in fact, in each case a *conversion of work into heat.*

It becomes, then, necessary to consider further what evidence we have as to the nature of heat itself. The old philosophers regarded heat as a subtle fluid, which passed into or out of bodies. It was thought that a certain amount of this fluid (which was termed "caloric") must be mingled with the particles of any substance in order to produce a certain temperature. The heat developed by friction or percussion was supposed to be due to an alteration in the heat capacity of the body concerned, the heat being, as it were, squeezed out by the blow or pressure. This view of the material nature of heat was generally held until the end of the eighteenth century, though suggestions had been made by Lord Bacon and others (without experimental proof) that heat might be rather a movement than a substance. Benjamin Thomson, afterwards Count Rumford, seems to have been the first to clearly set forth the inadequacy of the generally received theory. While superintending the boring of cannon in the arsenal at Munich, he was struck with the very large amount of heat produced by the friction of the boring bar against the metal castings, and he thought that an experimental investigation might enable him "to form some reasonable conjecture respecting the existence or non-existence of an igneous fluid." He therefore proceeded to make a series of careful experiments, with the object of finding out the source whence the heat produced might have been derived. He found that there was no appreciable difference between the heat capacity of the solid metal and of the fragments abraded by the action of the borer, so that the heat could not have been derived from the borings, owing to their capacity for heat being made smaller, as had been supposed to be the case when a body was reduced to powder or divided into small particles. Nor could the heat have come from the air, for it was still produced when the whole apparatus was placed in water, while it seemed extremely improbable that it should have come from the boring-bar or gun-metal casting, because heat was constantly escaping by these channels. Finding, further, that the source of the heat appeared to be *inexhaustible*, Rumford concluded that heat could not be a material substance, and that it was "extremely difficult, if not quite impossible, to form any distinct idea of anything capable of being excited and communicated in the manner the heat was excited and communicated in these experiments except it be *motion*." These experiments of Rumford were published about 1798, and a few months afterwards Sir Humphrey Davy showed that two pieces of ice could be melted by rubbing one against the other, even if the experiment was made in a vacuum, and with the surrounding bodies at a temperature below the freezing point. Thus the heat required to melt the ice must necessarily have been produced by the friction. The experiments of Rumford and Davy really disproved the material theory of heat; though Davy at first did not clearly realise this. It is to Dr. Joule of Manchester, however, that we owe the first quantitative experiments showing the exact numerical relation which exists between heat and mechanical energy.

The question which Joule set himself to answer was this: Can we get any amount of heat from a definite amount of mechanical work, or do we always get the same amount of heat? By means of a series of most careful experiments, extending over many years, he showed that the quantity of heat produced by the friction of bodies is strictly proportional to the work done, and that to generate, by mechanical means, enough heat to raise 1 lb. of water through 1° F., about 772 ft. lbs. of work must be done; in other words, if a weight of 772 lbs. falls through 1 ft. (or a weight of 1 lb. through 772 ft.) one such unit of heat would be produced in bringing it to rest. This value of 772 ft. lbs. (usually designated by "J") is known as "the mechanical equivalent of heat." The number of course varies when a different heat unit is taken. Using the centigrade thermometer, for example, instead of the Fahrenheit, the value is 1390 ft. lbs.

Joule's best known experiments were made about the year 1849, and consisted in the accurate measurement of the rise of temperature produced in a given quantity of water (or mercury) by the friction of metallic paddles caused to rotate rapidly in it by the descent of known weights through a measured distance.

"*Now, since heat can be produced it cannot be a substance, and since whenever mechanical energy is lost by friction there is a production of heat, and whenever there is a gain of mechanical energy in an engine there is loss of heat, and since the quantity of energy lost or gained is proportional to the quantity of heat gained or lost, we conclude that heat is a form of energy.*"—(CLERK MAXWELL.)

We have reason to believe that this energy is that of the motion of the molecules of a body, and that when a cannon ball strikes a target and is thereby deprived of its motion as a whole, this motion is not really lost, but is transformed into a new vibratory motion of the particles of the ball and target. A rough illustration of such a transformation may be made by fastening a number of bells to a large heavy hoop suspended to the ceiling; if this hoop be allowed to swing freely backwards and forwards, like a pendulum, no ringing of the bells will be observed; but if an obstacle, such as the hand, be opposed to the motion of the hoop, in the middle of its swing, the onward movement of the body, as a whole, is suddenly destroyed, and transformed into a vibratory motion of its parts, which causes the bells to clang.

4. **Kinetic and Potential Energy.**—We have seen that a body may possess energy in virtue of its *motion;* that the weight of a clock, for example, in the act of falling does a certain amount of work which it cannot do when the weight reaches the ground. But we have also seen that the weight when raised up (even when not in actual motion) is in a different condition as regards its power of doing work from the same weight when resting on the ground. The raised weight is in a *position of advantage*, with respect to the earth, in virtue of its being separated from the earth by a certain distance, whereby it is made ready to fall in obedience to what we conveniently call the force of gravity. It therefore possesses energy, or the power of doing work, which is not possessed by the weight after it has fallen.

We may then divide the energy of a system of bodies into two parts: (i.) *that part which is due to the relative motion of the parts of the system* (called its **kinetic energy**); (ii.) *that part which is due to the relative position of the parts of the system* (called its **potential energy**). It will be further seen, from the illustration considered, that the potential and kinetic forms of energy are mutually convertible. The system consisting of the earth, and a ten pound weight, raised to the height of 5 feet from the ground, may be said to possess 50 foot-lbs. of potential energy in virtue of the relative position of the weight and the earth. If the weight be allowed to fall freely, this potential energy passes into the kinetic form, and the weight reaches the ground with a considerable velocity, and in the act of striking the ground this energy of visible motion is converted into *heat.*

An ordinary *pendulum* furnishes an excellent illustration of this transformation. When the bob is at its highest point all the energy is in the potential form ; at the middle of its course, when moving fastest, all the energy is kinetic ; as the bob reascends on the other side of its lowest point it loses kinetic and gains potential energy, until, when it comes to rest for an instant at the end of its swing, the energy is again entirely in the potential form. If there were no resistance of the air or friction at the points of suspension, the pendulum would go on thus moving for ever ; owing, however, to friction, some of the energy is continually being converted into heat motion, and thus the pendulum ultimately comes to rest.

We have in the *solar system* another illustration of the constant change of potential into kinetic energy, and *vice versa ;* when the planets approach the sun there is a diminution in the potential energy of the system consisting of sun and planets, just as there is in the system of earth and pendulum when the bob approaches the ground, but in each case there is an equivalent gain of kinetic energy ; for we have already observed that the planets move faster in their orbits as they approach the sun. Conversely, on receding from the sun, and thus increasing the potential energy of the system, we find that their velocity (and so their kinetic energy) is diminished. Thus the sum of the two energies is always constant.[1]

References.—In Helmholtz's *Popular Scientific Lectures* (Longman's) a very clear and readable account of the Principle of the Conservation of Energy will be found under the title of "The Conservation of Force." The history of the doctrine is fully discussed in Tait's *Recent Advances in Physical Science* (Macmillan), a work which should be read by every student. An interesting account of Rumford's work will be found in Garnett's *Physicists* (Heroes of Science Series, S.P.C.K.).

Section II.—The Forms of Energy and their Transformations.

I. **nergy of Masses.**—The kinetic energy of a moving body may be termed **energy of visible motion.** We have examples in nature of this kind of energy in the movements of planets and meteors, in a falling rock or avalanche, in wind and rain and running streams. The relation between the *velocity* of a moving body and its kinetic energy is expressed by the law of squares, which states that when the velocity is doubled the energy is increased fourfold; with three times the velocity we have nine times the energy, and so on.

In a rain-cloud, a head of water, and a mass of snow upon a mountain, we have instances in Nature of the potential energy possessed by masses when raised to a height. This form of energy has been termed **potential energy of visible arrangement.** Besides the above, and similar examples in which the energy is due to a position of advantage with respect to the force of gravity, we have instances of this form of energy of position in a bent bow, or a coiled spring, where work has been done against the elastic forces of the bodies concerned, and a position of advantage with respect to these forces thereby gained.

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[1] It is possible that all energy is *really* kinetic; thus in the system consisting of the earth and a raised weight, it may be that the energy is due to some *motion* in the medium surrounding both earth and weight that presses them together. *See* a paper by Prof. Oliver Lodge in "*Proceedings of the Physical Society*, vol. xii., part 3. (Dec. 1893.)

2. **Molecular Energy.**—We have seen that **heat** may be regarded as the energy of the vibratory motion of the molecules of which matter is composed, and that when the motion of visible masses is arrested it is converted into the motion of invisible molecules. Similarly we have a potential form of molecular energy comparable to that possessed by a raised weight and the earth. When a solid passes into a liquid, or a liquid into a gas, a certain amount of heat disappears or becomes "latent" (page 53). The heat energy is used up in overcoming the cohesion of the particles, and is stored up in the potential form of **energy of molecular separation.** The molecules have been pushed farther apart, and are thereby placed in a position of advantage with respect to the force of *cohesion* or *molecular attraction*, which tends to bring them together. When we allow them to approach again, this energy re-appears as heat. We have another example of this form of energy in a rod of metal expanded by heat, in which case mechanical work may be done in the process of cooling, as in the well-known practice of "shrinking" tires on to wheels.

3. **Chemical or Atomic Energy.**—When a current of electricity passes through acidulated water, we have learned that the water is decomposed into its constituents, oxygen and hydrogen. The same decomposition may be brought about by the action of very great heat. In this case, heat is used up or disappears, and is converted into another form of energy which may be conveniently termed **energy of chemical (or atomic) separation.** The system consisting of uncombined oxygen and hydrogen very evidently pos-

sesses energy, for by exploding the mixture in a cannon we could give a great velocity to the cannon ball. The particles of oxygen and hydrogen are in a position of advantage with regard to the force of chemical attraction or affinity, which tends to cause them to combine. They are like the raised weight, or the bent bow. When we cause them to combine, by applying a light or spark (analogous to the action of loosing the bowstring, or dropping the weight), the atoms may be supposed to rush together (the energy thus momentarily taking a form which may be termed **atomic motion**); energy of chemical separation disappears, and an equivalent in the form of heat or of visible motion appears. In gunpowder and other explosives, as well as in ordinary fuels (together with the oxygen of the air), we have well-known examples of the potential energy of separated atoms. In all cases of chemical combination we find that heat is produced, and in all cases of chemical decomposition heat (or some other form of energy) must be used up or disappear in order to supply the energy of chemical separation which appears.

4. **Electrical Energy.**—But the energy in cases of chemical combination need not all appear as heat; a part of it may take the form of **electricity in motion.** If a plate or rod of ordinary zinc be dipped into dilute sulphuric acid, we have seen that zinc sulphate is formed and hydrogen gas liberated; in this action a great deal of heat is produced, the zinc may, in fact, be said to undergo a kind of slow combustion. If, however, the zinc be quite pure, or if ordinary zinc *amalgamated* or covered with a coating of mercury be used, it is found that no action takes place, unless a rod of some other metal (as copper or platinum) or of carbon, be dipped into the acid—not touching the zinc—and joined to the plate of zinc by a metallic wire outside the liquid, the whole arrangement forming what

is termed a simple **voltaic cell** (Fig. 42). Under these circumstances the zinc dissolves, sulphate of zinc is formed, and hydrogen is evolved as before (appearing, however, at the surface of the unattacked copper or platinum plate), and the wire acquires certain properties which are said to be due to a current of electricity passing along it. This current possesses energy, for it can be converted into *heat*, as in an ordinary incandescent lamp in which a filament of carbon is raised to a white heat by the passage of the current, or it can be made to perform *mechanical work*, as in an electro-motor, or to do *chemical work*, as in electro-plating, or the electrolysis of water. Now, it has been shown by Favre that when heat is being produced, or work being done by the current outside the cell, a proportionally *smaller* amount of heat is produced in the cell itself. We have thus in a galvanic cell and electro-motor an instance of the *conversion of energy of chemical separation into energy of electricity in motion*, and of this again into energy of visible motion. In a dynamo machine, in which a current is produced by the rotation of coils of wire between the poles of powerful magnets, we have the reversed action of *energy of visible motion being converted into electricity in motion.* Work is done in moving the coils against the magnetic forces, and the energy of the current is the equivalent of the work thus done.

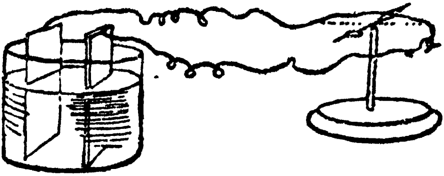

Fig. 42.

In the case of an ordinary frictional electrical machine, work is done against friction by rubbing, and an equivalent is produced in the form of **energy of electrical separation.**

Two oppositely electrified bodies tend to attract one another, they are, therefore, when separated, in a position of advantage with respect to this force of electrical attraction, which tends to cause the separated electricities to unite. When they do unite, the energy of electrical separation disappears, and an equivalent in the form of a momentary electric current, and ultimately, usually of heat and light appears. The exact nature of electricity is somewhat obscure, but it is probable that both electric and magnetic effects are due to the propagation of some state of stress through a medium known as the luminiferous ether (*see* below).

5. **Radiant Energy.**—The process by which heat passes from one body to another, not in contact with it, as from the sun to the earth, or from a fire to the opposite end of a room, is termed *radiation.* This radiation, though often conveniently spoken of as "radiant heat," is not in itself heat, but if it falls upon an ordinary surface which absorbs it, it is converted into heat. "Radiant heat" is believed to consist in a vibratory or wave motion of the **luminiferous ether,** a substance unlike any ordinary form of matter, which is supposed to fill all space. The evidence for this belief is briefly that radiant heat appears to be of the same nature as *light*, for both travel in straight lines, with the same velocity (when the sun is eclipsed, for instance, its heat and light are both cut off at the same instant), both are similarly affected by mirrors and lenses (as shown in the case of an ordinary "burning glass"), and both are subject to the same laws of interference and polarisation:—phenomena which will be found described in works on Light. Now, it was formerly imagined that light consisted of a great number of small particles shot out from a luminous body in all directions, and reflected at smooth surfaces like elastic balls. This **corpuscular theory** was favoured by Newton, and he was able to explain by it the

known laws of reflection and refraction of light. In order to account for the **refraction** or bending of a ray of light out of its straight course, when it passes from one medium to another, he was obliged to assume that light travels faster in dense media (like glass or water), than in rare media (like air.) Foucault, however, has proved experimentally that the reverse is actually the case; the velocity of light in water being less than in air. This fact, together with the failure of the corpuscular theory to satisfactorily explain many of the observed phenomena of light, has led to the overthrow of Newton's theory, and to the establishment of the **wave theory** propounded by Huyghens in 1672, and supported by Thomas Young, Euler, and others, according to which, light is regarded as consisting of a series of waves (see p. 127) set up in the ether by the vibrations of molecules of matter. There are many considerations which lead us to believe that COLOUR depends upon the *lengths* of these waves, which are in all cases very small, ranging from about ·0000167 of an inch in the case of violet light to ·0000266 of an inch in the case of red light; beyond these limits there are, however, smaller and larger waves, which can produce chemical and heating effects, but which do not produce the sensation of light. From the recent experiments of Hertz and others on electro magnetic disturbances, it appears that *electrical oscillations* can be produced which have many of the properties of light waves; they are, for example, reflected and refracted in just the same way as light, and travel with the same velocity. The chief difference between them is that of wave-light; these electrical waves (which do not affect the eye, and which can pass through certain substances opaque to light) being much longer than the waves that affect the eye, ranging from 2 or 3 inches to many yards.

The term **radiant energy** may be conveniently used to include both light and "radiant heat." The *rate* at which a body radiates heat depends upon the nature of its surface; those surfaces which absorb heat most also radiate the best. Lamp black absorbs and radiates heat waves well; polished metal surfaces are very bad radiators and absorbers, but very good reflectors of heat waves.

This difference in absorbing power is well seen in Crooke's *radiometer*, in which four small discs or vanes of aluminium covered with lamp black on one side only, are mounted upon a pivot in a glass globe from which the air has been nearly all removed by means of a pump. When exposed to light the black sides of the vanes absorb the radiation most, and become warmer; the air particles striking these sides rebound with increased velocity, and the vanes are thus driven backward by the greater recoil.

In the formation of a **photographic image** we have an instance of the conversion of radiant energy into energy of chemical separation; the rays of light falling upon the prepared photographic plate do work in overcoming the force of chemical affinity, instead of being, as in most cases, entirely converted into absorbed heat. Another very important example of this transformation is to be found in the action of green plants on the atmosphere under the influence of sunlight (see p. 148).

References.—Balfour Stewart's *Conservation of Energy* (Int. Sc. Series; Kegan Paul); Tait's *Recent Advances in Physical Science*; and the same author's *Light*; see also a lecture by Stokes on the luminiferous ether reported in *Nature*, July 27, 1893; and for theories of magnetic and electrical energy, Lodge's *Modern Views of Electricity* (Nature Series. Macmillan). A detailed classification of the forms of energy will be found in a suggestive paper by Prof. Lodge in the *Philosophical Magazine* for October, 1879.

Section III.—Natural Supplies of Energy and their Sources.

1. **Fuel and Food.**—Among potential forms of energy, one of the most important is the energy of chemical separation stored up in fuel, or rather in the system consisting of ordinary fuels and the oxygen of the air, without which the fuel would be of no value as a source of heat and power. The food of animals may be regarded as a kind of fuel, for however much foods may vary in their nature, nearly all foods *contain combustible material;* that is, they can combine with the oxygen of the air, heat being evolved in the process. They consist essentially of compounds containing carbon and hydrogen, combined with a small quantity of oxygen, and often with nitrogen. When strong sulphuric acid is poured upon lump sugar, a black frothy mass of charcoal is left, owing to the abstraction of the oxygen and hydrogen by the acid. The combustible nature of fats is a matter of common experience, while such foods as bread and meat, which we do not so usually regard as combustible, may, if previously dried, be readily burned in oxygen. An animal takes in ordinary food and air, and burns the food by the aid of the oxygen of the air, the hydrogen being converted into water, and the carbon mainly into carbonic acid gas, whose presence in respired air we can easily prove by breathing into a small quantity of clear lime water, which will be quickly turned milky (page 57). The peculiar nature of the animal organisation enables this process of combustion to go on at comparatively low temperatures. An animal may, then, be compared with a boiler and steam-engine. In the furnace, coal is burned, energy of chemical separation disappears, and this energy re-appears in the form of heat and mechanical motion. The animal is certainly

not adapted for consuming coal, but the transformations of energy are of a precisely similar kind, the supply of heat and of energy in the form of animal movements being furnished by the disappearance of an equivalent amount of energy of chemical separation.

In tracing the energy of fuel and food to its ultimate source, we must consider the chemical changes which go on in the life of PLANTS—for the food of animals is directly or indirectly of vegetable origin, while our commonest form of fuel is the remains of a vegetation which once existed upon the surface of the earth. Under the influence of solar radiation, green plants have the power of taking in carbonic acid gas and water, forming from these materials organic matter, such as starch and sugar, and giving back the excess of oxygen, in the free state, to the air. This change may be roughly represented by the following equation, though it is really much more complex:

$$\begin{array}{ccccccc} CO_2 & + & H_2O & = & CH_2O & + & O_2 \\ \text{Carbonic Acid Gas.} & & \text{Water.} & & \text{Starch.} & & \text{Oxygen.} \end{array}$$

This evolution of oxygen by green plants may be easily demonstrated by exposing to sunlight a flask (Fig. 43) filled with water, saturated with carbonic acid gas, in which some fresh green leaves have been placed. An inverted test-tube filled with water is placed, as shown, to receive the oxygen, which may be tested by its action upon a glowing splinter of wood.

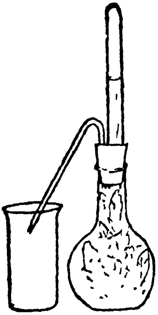

Fig. 43.

Owing to this action of plants, the accumulation of carbonic acid gas and the diminution of oxygen in the atmosphere, which would otherwise be caused by animals, are checked, and the average composition of the air remains practically constant. The production of organic matter and oxygen from carbonic acid and water, evidently implies the production of a certain amount of potential energy of chemical separation. This supply is furnished by the *disappearance of radiant energy*. When the solar radiation falls upon an ordinary surface, it is all converted into heat, but when it is absorbed by green plants, some portion of it is converted into energy of chemical separation. It will thus be seen that all the energy exhibited by animals, as well as all the energy derived from the combustion of wood and coal, is ultimately derived from the sun.

2. **A Head of Water.**—In this case we have also a supply of potential energy due to solar radiation. Under the influence of the sun's heat evaporation takes place from the surface waters of the earth, and the water vapour rises to a height whence it may be condensed as rain or snow, and stored in elevated positions, in virtue of which the condensed vapour possesses potential energy.

3. **Tidal Energy.**—In using tidal water power, we are drawing upon a different source : the tides being, as already noticed, due to the attraction of the sun and moon upon the surface waters of the earth, and to the earth's rotation on its axis. The energy is really abstracted from the motion of rotation of the earth, and the rate of this rotation appears to be very slowly lessened by the *tidal friction*, which acts like a brake upon the lithosphere.

4. **Winds and Currents.**—Winds, as we have seen, are due to unequal heating of the air by the sun, their directions being modified by the earth's rotation. The kinetic energy of ocean currents as well as of running streams is likewise evidently traceable to the sun.

5. **Internal Heat of the Earth.**—The energy manifested in the phenomena of geysers and hot springs, volcanoes

and earthquakes, and other movements of the earth's crust (see ch. v.), is derived from the high temperature of the earth's interior, which is gradually becoming cooler.

6. **Electrical and Magnetic Energy.**—The supply of energy necessary for the production of such electrical manifestations as an ordinary thunderstorm, is derived from atmospheric changes, such as winds, and the evaporation and condensation of water, which are all the effects of solar radiation. That lightning is simply a gigantic electric spark (often a mile or so in length) was first proved (in 1751) by the well-known kite experiment of Franklin, in which sparks were drawn from the wet string attached to a kite sent up into a thunder cloud. The irregular form of lightning, which photographs show to be rather sinuous than zigzag, is due to the unequal resistance of different parts of the air. Thunder is due to the air waves set up by an inrush of air particles to fill up the partial vacuum resulting from the sudden expansion of the air intensely heated by the passage of the current. Since light travels at the rate of 186,000 miles a second, and sound at the rate of only about 1100 *feet* a second, the distance (in feet) of a thunder cloud may be roughly estimated by multiplying this last number by the number of seconds interval between the appearance of the flash and the sound of the thunder. The beautiful coloured luminous displays, known as the aurora borealis (or northern lights), appear to be produced by electrical discharges in the rarefied upper strata of the air (usually from about 45 to 100 miles high), just as similar luminous effects on a small scale are seen when electric discharges are produced in a Geissler or vacuum tube containing rarefied gases.

The magnetism of the earth itself, which causes a freely suspended magnetic needle to set in a N. and S. direction, is probably largely due to electric currents maintained by the earth's movement of rotation.

7. **Origin of the Sun's Heat.**—It will be seen from the above that the main sources of terrestrial energy are the earth's own store of internal heat, its movement of rotation, and (most important of all) the supply of radiant energy which it constantly receives from the sun.

The heat energy of the sun itself is most probably caused by its slow contraction due to gravitation, the energy of visible separation being converted into molecular motion. It has been calculated that a decrease of the sun's diameter of about 220 feet a year, or rather more than four miles in a century, would be sufficient to maintain the present supply of heat.

References.—Works mentioned on page 146, and the relevant portions of Tait's *Thermodynamics*.

Section IV.—Degradation of Energy.

1. **Tendency of Potential Energy to become Kinetic.**—A consideration of the various examples which have been given of the transformations of energy leads to the conclusion that there is a constant tendency for all systems to increase their kinetic at the expense of their potential energy; the raised mass of snow ultimately falls as an avalanche; the head of water gives rise to the running stream or waterfall; the coiled spring unbends and does work; the separated atoms rush together in chemical combination, and so on.

2. **The Ultimate Form of Energy.**—It will be further seen that the ultimate form assumed by the energy in all these cases is *heat*. There is everywhere a continual change of other forms of energy into the form of heat, which is pro-

duced, as we have seen, wherever visible motion is arrested. Now, it was long ago shown by Carnot that mechanical work can only be got out of heat, when heat passes *from a hotter to a colder body* (as in the case of a steam-engine, where the heat of the fire passes to the water in the boiler and thence to the colder water of the condenser), and even then only a portion of the heat is available for the purpose of producing work. The heat of a body which cannot be further cooled can in no wise be changed into any other form of energy. Hence, although there is the same amount of energy in a given quantity of heat, at whatever temperature it may be, the *availability* of this heat energy, or its power of being transformed, is not the same in the case of low temperature as it is in the case of high temperature heat. Now, the heat of a hotter body is always striving to pass to colder bodies by the various processes (conduction, convection, and radiation) by which heat is diffused, so that high temperature heat is continually being let down or degraded to low temperature heat, which cannot be converted back again into work. Hence, it follows that the ultimate result of the continual conversion of mechanical motion, and of chemical and electrical energy into heat motion, will be that, while the total *quantity* of energy in the universe remains constant, its *quality*, as regards usefulness, or availability for the purpose of producing work, will be always deteriorating, until finally the whole of its energy will become transformed into the unavailable form of universally diffused heat. This is Lord Kelvin's theory of the dissipation or degradation of energy.

References.—Works mentioned on pages 140, 146, also article by Lord Kelvin, "The Dissipation of Energy," in *Fortnightly Review*, March, 1892.

CHAPTER V.

HOW THE MATERIALS OF THE EARTH'S CRUST WERE FORMED.

Section I.—Principles of Rock Classification.

1. **The Method of Geology.**—The occurrence of sea-shells and other remains of marine organisms in rocks, early led to the conclusion that the earth's surface had been in past times subject to various changes. In the earlier speculations as to what these changes had been, and how they had been brought about, the most wild and fanciful hypotheses were suggested, and comparatively little advance was made until Hutton (1726-1797) pointed out that the only satisfactory method in geological investigation was to *work back from the seen and known to the unseen and unknown;* that if we wish to obtain clear ideas about long past changes on our earth's surface we must begin by carefully observing the changes of modern times. These changes were first systematically investigated and described by Lyell. They may be classed as those due to (i.) **epigene**, or *surface* agencies, by which the materials of the earth's crust are worn away; (ii.) **hypogene**, or *underground* agencies, producing earthquakes, volcanoes, and slow movements of the earth's crust.

2. **The Origin of Sandstone and Limestone.**—Applying Hutton's principle to the problem of determining the history and origin of the common rock-masses, of which the surface portions of our earth are composed, we must first examine

into the nature and composition of each rock material, and then try to find out if any similar material is being produced by known processes at the present time.

If we examine a block of common RED SANDSTONE, we shall find that it is principally composed of grains of quartz cemented together; probably it will contain bits of mica, and partly decomposed felspar as well; all the particles having the appearance of being more or less rounded and worn; in many cases a little pressure in the hand will be sufficient to crush the rock into a mass of reddish sand; but, in other cases, prolonged boiling in strong hydrochloric acid may be necessary to attack and loosen the cement which binds the grains together. Most commonly this cementing material is found to be a sort of iron rust (red oxide of iron), which, being dissolved by the acid, leaves a mass of whitish sand, just like the sand of a modern sea-shore. Sometimes the cementing material is carbonate of lime, in which case the rock effervesces when placed in acid. If we next examine the appearance and structure of the sandstone on a larger scale, as it occurs in a quarry or cliff, we notice that it has a well-marked bedded, or *stratified* arrangement (3 in Fig. 44), and in some cases we may find that it contains *fossils*, or the traces of animal or vegetable organisms which have got buried in it. Now, in the sand of the sea-shore or of a river-mouth, which we can observe being formed at the present day, we find all these characters: it is composed of rounded grains, mainly of quartz; it is arranged in layers; and it often contains animal and vegetable remains. It is true that the sandstone of the quarry is firmer and more compact; but, even in the same quarry, we may find a transition from very hard stone to a much less coherent material; and we know that loose and incoherent substances may be compacted into firm and solid masses, both by mere pressure, and by the infiltration of water containing cementing materials in solution; for we find that beds of oyster-shells and other loose materials get converted into a solid mass by an infiltration of calcareous cement deposited from water just in the same way that carbonate of lime is deposited in limestone caves (p. 122).

Since, then, the modern sand material is always seen to result from the wear and tear of pre-existing rock-masses by rain, frost, rivers, or the waves of the sea, which break away fragments of rock, and by constant friction grind them down into small more or less rounded grains, which are ultimately

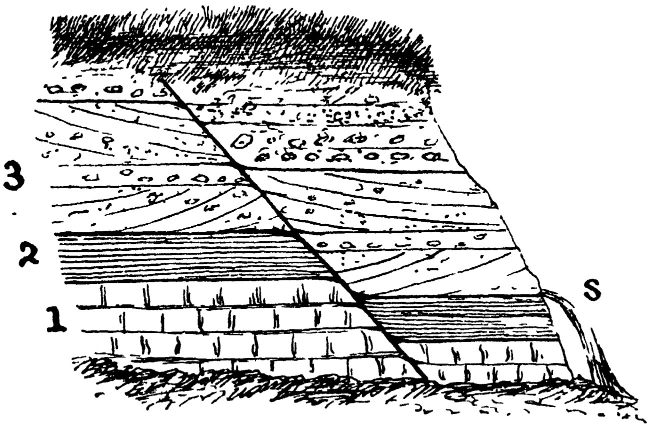

Fig. 44

deposited as a sediment, we conclude that the rocks of a sandstone quarry were at one time formed and arranged in layers by moving water in a similar way. The planes of stratification, due to successive layers of deposition, may be either flat and regular, when the beds have been deposited in water disturbed by no rapid tides or currents; or irregular and inclined, as shown in the upper part of Fig. 44, when the beds have been laid down in water exposed to the action of changing currents. When the strata have been laid down in shallow water, *surface markings*, such as ripple-marks, sun-cracks, rain-prints, and markings left by animals, are often found upon their bedding surfaces. These structures afford additional evidence of the sedimentary origin of the rocks. On examining the structure of the rocks in a LIMESTONE quarry (1, Fig. 44) we shall probably notice a similar stratified arrangement of the materials, suggesting that it too has an *aqueous* origin. Now limestone is, chemically, carbonate of lime, and the only way in which we find deposits of this substance being formed on a very large scale at the present time is by the process in which various marine organisms, such as the *coral polype*, abstract the dissolved lime compounds in sea water, and construct therewith a hard calcareous skeleton or shell. When the organisms die their soft parts rot away, but the hard shells or skeletons (partly broken up by the action of the waves, and a good deal compacted together by pressure and

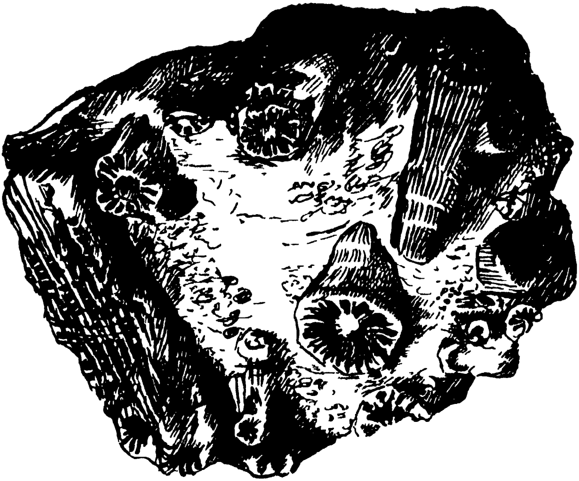

Fig. 45

the infiltration of water containing cementing material) remain to form rock-masses, like the Great Barrier Reef which stretches for more than 1000 miles along the N.E. coast of Australia

Hence we are led to think that the limestone of our quarry may have had a similar *organic* origin, and this supposition is soon confirmed by an examination of polished slabs or weathered specimens, which reveal the presence of undoubted corals, shells, sea-lilies, and other organisms, not perhaps exactly like those now existing, but sufficiently like them to leave no doubt as to their relationship. Such weathered corals are shown in Fig. 45, while Fig. 46 represents the stems of sea-lilies (crinoids or encrinites) in a block, partly weathered and partly polished, of "encrinital marble." The way in which this natural dissection of the rock results from exposure to the weather will be sufficiently clear, when it is remembered that rain water, owing to the presence of carbonic acid in solution, has a considerable power of dissolving limestone, and that the more crystalline calcite of the unbroken coral or crinoid resists the solvent

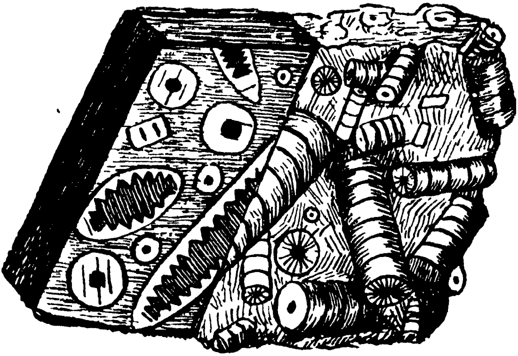

Fig. 46.

action better than the more granular portion of the rock, formed of their comminuted fragments.

In many cases too, where the unaided eye is unable to detect in limestones any traces of such organisms, a microscopic examination of thin slices of rock, or (in the case of soft chalk) of the washings of the powdered material, reveals the presence of innumerable small shells of *foraminifera*, such as are now found to be accumulating to form the calcareous oozes of the deep sea (Fig. 47). Limestone, then, is usually an *organically formed* aqueous rock, while sandstone may be said to be *mechanically formed* Limestones redeposited from solution as stalagmite or tufa, in the manner described on page 122, are *chemically formed* aqueous rocks.

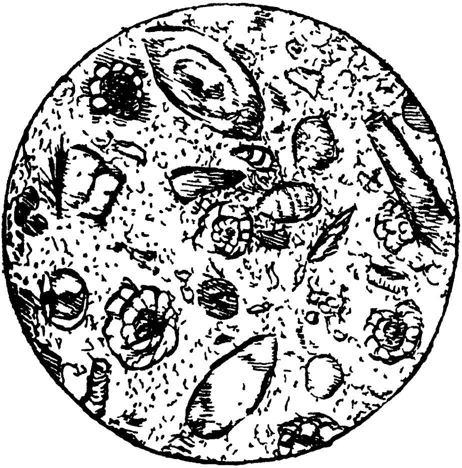

Fig 47 Foraminiferal Limestone (highly magnified)

3. **The Origin of Basalt and Granite** —On examining the BASALT ROCKS of Fingal's Cave or the Giant's Causeway (Fig. 48) we observe characters quite distinct from those of the rocks we have been considering. They are not

arranged in regular layers or strata, but present the appearance of roughly hexagonal columns; they contain no fossils, and when examined in thin sections under the microscope are seen to be composed of a mass of small crystals with sharp angles, not having the appearance of being water-worn like the grains of a sandstone (see Fig. 49, representing the microscopic structure of a basalt, composed of crystals of (1) augite, (2) olivine, (3) felspar). Similar six-sided columns are to be found in the lava streams of volcanoes, such as Vesuvius or Etna, where they result from the contraction, on cooling, of the molten material. These lavas, moreover, are composed of similar materials, and present under the microscope a crystalline structure just like that of the basalt. We may, therefore, conclude that it has had a similar volcanic origin. This conclusion is confirmed by the fact that artificial basalts have been produced by Fouqué and Lévy by prolonged fusion and slow cooling of the powdered minerals of which basalt is essentially composed: while we have a further proof of the former highly heated condition of the basalt in the alteration sometimes found to have been produced by the action of the heat upon neighbouring rocks, coal, for example, having been converted into a cindery or sooty material, and clay baked into

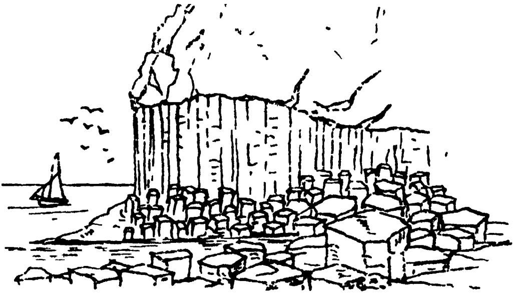
Fig. 48.

a kind of porcelain. The rocks of a GRANITE quarry present features somewhat similar to those of basalt. They are not stratified, they do not contain fossils, and they are composed of crystals of felspar, mica, and quartz, as already noted. Hence, we are led to think that granite is also an *igneous* rock, even though we are not able to find any examples of granite being actually formed at the surface of the earth in modern times, and though all attempts to artificially produce a rock like granite in the laboratory have so far failed Many of the older geological writers maintained that granite was an aqueous rock, deposited as a crystalline precipitate from the earth's primordial hot ocean, but Hutton showed that in the Highlands of Scotland, granite veins were seen traversing other rocks and altering them, thus conclusively proving that the granite was younger than the rocks it had penetrated, and that it had been injected into crevices when in a highly heated state. The crystalline structure of granite [see Fig. 50, representing the microscopic appearance of a granite, composed of crystals of (1) quartz, (2) felspar, (3) mica] is much coarser than that of basalt, and it is proved by experiments that when a lava

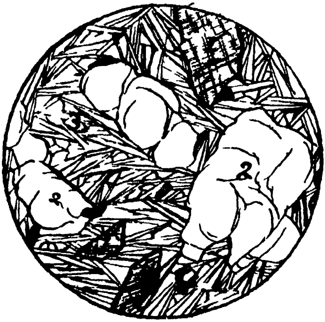

Fig. 49.

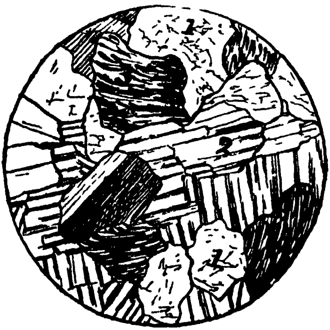

Fig. 50.

cools quickly, it forms a glassy mass with very little crystalline structure, but that when cooled very slowly it becomes more coarsely crystalline. Hence we conclude that granite has cooled and consolidated very slowly, probably at great depths below the earth's surface, its present appearance at the surface being due to subsequent upheaval, and to the wearing away of the superincumbent rock by the destroying agencies of rain, frost, and running water, which will be considered in the next section.

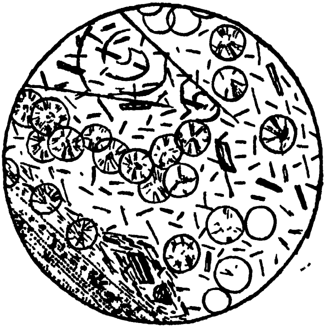
Fig. 51.

Since such glassy lavas as obsidian and pitchstone have practically the same chemical composition as granite, it seems likely that, if we could trace these lavas deep down into the interior of a volcano, we should find them passing into rocks of granitic type. Figure 51 represents the appearance under the microscope of an OBSIDIAN, showing the *flow structure* due to the movements of the viscid mass, in which the small lath-shaped crystals (*microliths*) have been carried along so that their long axes are more or less parallel to one another, and the *perlitic structure* due to the formation of curved joints or cracks as the material contracted on cooling. The incipient forms of crystallisation seen on the left of the figure are known as *crystallites;* the bands of crystallites are often seen to spread out round previously formed larger crystals. Some of the crystallising material has separated from the glassy magma in the form of small globular aggregations (possessing a fibrous structure) known as *sphaerulites.* (This figure, as well as figures 49 and 50, is copied from Fouqué and Lévy.)

A like examination of other rocks leads to the conclusion that nearly all the rocks of which the earth's crust is composed can be classed either as *aqueous* or as *igneous*. The **aqueous rocks** as a class are for the most part *stratified*, *non-crystalline*, and *fossiliferous;* the **igneous rocks** are usually *unstratified*, *crystalline* and *unfossiliferous*.

References.—Prof. A. H. Green, *Physical Geology* (Longmans), chapters ii. and iv.
Sir A Geikie, *Geological Sketches* (Macmillan).
Sir C. Lyell, *Principles of Geology* (Murray).
For the microscopic structure of rocks Teall's *British Petrography* (Dulau & Co.) is the standard English work.
An interesting lecture, by A. Renard on *The Artificial Production of Volcanic Rocks*, will be found in *Nature* xxxix. (1889), p. 271.

Section II.—Denudation and Deposition. The Aqueous Rocks.

1. **Classification of Denuding Agencies**—It will be necessary to consider a little more in detail the surface agents of change now at work in modifying the earth's crust. The process by which the surface of the ground is broken up or disintegrated and the fragments removed is termed **Denudation.** **Deposition** is the laying down of the material thus removed. The principal AGENTS OF DENUDATION (acting in conjunction with *gravity*) are (i.) *air and rain*, (ii.) *running water*, (iii.) *frost and ice*, (iv.) *the sea*. The first three are sometimes grouped under the head of *sub-aerial* or *atmospheric*, as contrasted with *marine* denudation. In briefly considering the action of these various denuding agencies it will be convenient to regard the action in each case as consisting of the three separate processes of EROSION, TRANSPORT, and DEPOSITION.

2. **Geological Work of Rain and Rivers.**—The mechanical action of rain as an agent of erosion is strikingly seen

in the formation of earth pillars (Fig. 52), due to the continued wasting away of comparatively soft strata containing hard stones, which throw off the rain-drops and thus protect the mass beneath. Rain also acts chemically upon rocks by dissolving soluble material, as we have already learned in the case of limestone. When rain, after sinking into porous soils and rocks, meets a stratum of impervious material like clay, it is usually thrown out in the form of springs (Fig. 44, S), and, when the slope of the beds is favourable, the lubrication of the clay surface, and consequent undermining of the upper porous strata, often leads to the production of **landslips**.

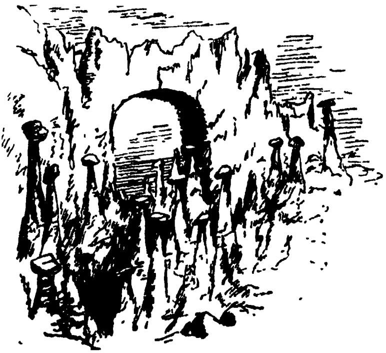
Fig. 52.

The disintegration of rocks is often aided by the action of *plants*, whose roots, penetrating into joints and crevices, act like wedges in forcing them asunder; plants also furnish certain acids by their decay, and thus increase the chemical action of rain on rocks.[1] On the other hand a coating of turf or moss often serves as a protection against the mechanical action of rain and rills. We may note here the action of *heat and cold*, which, in countries subject to great extremes of temperature (as in the rainless plateau region of Western America with a daily range of 80° F.) leads to much fracturing and crumbling of rock masses, owing to sudden expansion and contraction. *Wind*, too, in exposed situations, plays a not unimportant part in modifying surface features, the isolated blocks and pinnacles of rock, such as are to be found in large numbers in the millstone grit district of Derbyshire and Yorkshire, being mostly the work of wind-blown sand.

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[1] See *Humus Acids*, by Alexis Julien, in Proc. American Assoc. for the Advancement of Science. 1879.

The erosive work of *streams and rivers* is largely due to the friction of the materials driven by the current against the sides and bottoms of water courses. This erosion is largely increased in times of flood, when the scour is often very great, and the channel of the stream is correspondingly deepened. Vertical holes, called "pot-holes," often of great size, are worn out, even in the very hardest rocks, by means of stones kept in whirling motion by the action of the current; and the frequent occurrence of such pot-holes at considerable heights above the present level of the stream, proves that the formation of the steep-sided valleys or gorges so frequent in the upper or *torrent* portions of river courses, is mainly due to the action of the running water and the moving stone, and not (as was formerly imagined) to the work of subterranean forces, which forcibly rent the rocks asunder; though it may be that in the formation of such colossal trenches as the cañons of Colorado, underground movements have had some share. In the recession of a waterfall by the undermining of the ledge of rock over which the water flows (as in the case of Niagara) we have a very common origin of steep-sided or U-shaped valleys. Where the rocks are comparatively soft and the climate more or less humid, valleys are generally broad and open, or V-shaped, owing to the wearing down of the sides by rain and rills. As TRANSPORTING agents, rivers remove both their own and other debris. The amount of material carried by rivers both in suspension and solution is greater than we should at first sight imagine: thus it has been estimated that the Mississippi carries every year 15 million tons of material in invisible solution, and 383 million tons of visible suspended matter into the sea. This enormous amount of material evidently comes from the ground drained by the Mississippi river, whose basin is thus being slowly worn away.

Since the carrying power of a stream varies with its velocity, the matter carried in suspension is dropped when the velocity is checked, and DEPOSITION takes place. Thus, where a river leaves the mountains and enters a more level region, a fan-shaped mass of sediment, or **alluvium**, is usually found, and when a river enters a lake or the sea it frequently deposits much of its burden of gravel, sand, and mud, in the form of alluvial bars and deltas (so called from their shape, like the Greek letter Δ). We have examples of this action, on a very large scale, in the deltas of such rivers as the Mississippi and the Ganges, the former having an area of more than 12,000, and the latter of, probably, 50,000 square miles. Of deposits, largely due to the action of wind and rain, we may note the *growth of dust* and formation of ordinary vegetable *soil.* This soil is formed, partly by the crumbling and decay of the solid rock beneath (hence its variation in composition according to the character of the rocks from which it is mainly derived), partly by the accumulation of wind-borne sand and dust, and partly by the decay of vegetable matter.[1] Darwin has shown that the formation of vegetable mould is largely due to the action of common earthworms.[2] According to Professor Drummond, the white ants in Central Africa produce similar effects, large quantities of material being brought to the surface to form their hills, which are ultimately washed down by the violent rains.

Wind-blown sand occasionally accumulates to form great *dunes*, which, on the coast of Holland, sometimes attain a height of 250 feet. (For chemical deposits, due to rain and streams, see chapter iii., section 4.)

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[1] See *Dust and Soils*, by Clement Reid. *Geol. Mag.* April, 1884.

[2] Darwin: *The Formation of Vegetable Mould through the Action of Earthworms.* (Murray.)

3. **Ice Action.** — The action of frost in causing the fracture of rock-masses has already been mentioned (p. 52). Its effects are seen in the jagged peaks and narrow points *(aiguilles)* of many mountain summits, and in the great piles of angular fragments (known as **screes**) often to be observed at the foot of mountain slopes and precipices. Ice acts also in a very striking manner by means of GLACIERS. In places where the mean annual temperature is below 0° C. the condensed atmospheric moisture falls chiefly as snow, much of which remains unmelted throughout the year. A line, termed the *snow-line*, can be traced, above which the summer heat is insufficient to cause the disappearance of the snow accumulated in winter. In Spitzbergen it comes down to the sea level, in Norway it is 6000 feet high, in the Alps nearly 9000, and in the Andes 15,000 feet above the sea. The snow-covered regions above the snow-line are *drained* partly by huge falls of snow or avalanches, but chiefly by means of ice rivers, or glaciers. The loose fallen snow gradually assumes a granular structure forming a more or less compact mass known as *nevé* or *firn.* The weight of the upper layers of snow in the nevé, together with the freezing of water, thawed at the surface and filtered down, converts the lower part into solid ice, which usually shows a veined structure. This ice then moves slowly down the valleys, the middle and top moving faster than the sides and bottom, where there is more friction. By means of a row of stakes erected across the glacier, which gradually assume a curved form owing to the more rapid movement of the central ice, this slow movement can be observed and measured. The Mer de Glace moves 33 inches in 24 hours in summer, and about 18 in winter. The exact causes of glacier motion have been much debated amongst physicists. A glacier moves like a plastic body, but until recently, experiments had not shown a true plasticity in hand specimens of ice. The recent experiments of Messrs. M'Connel

and Kidd have proved that while homogeneous ice is not plastic, ordinary glacier ice, which consists of a conglomerate of crystal grains of varying size, yields gradually like a viscous body to the continued action of stresses applied in certain directions.[1]

When a level is reached where the melting of the ice is in excess of the supply (in the Alps at about 5000 feet above sea level) the glacier terminates in a muddy stream. In more northern regions the glaciers may flow down to the sea, where fragments break off forming icebergs. In both cases, the snow which originally came (in the form of water vapour) from the ocean is restored to it.

During the descent of a glacier, fragments of rock from crags and cliffs accumulate on its sides to form fringes of angular blocks of all shapes and sizes termed **lateral moraines.** When two glaciers unite, the left lateral moraine of the one joins with the right lateral moraine of the other to form a **medial moraine.** Many of these fragments fall through fissures or *crevasses* (caused partly by the irregularities of the bed of the glacier and partly by the unequal rate of motion of the ice in different parts), and becoming embedded in the base of the ice, are crushed and ground against the hard rocks of the glacier bed, which thus become smoothed down, scratched, and striated, and sometimes polished. Rounded bosses of rock thus produced are termed *roches moutonnées.* The fragments themselves also become grooved and polished. When the glacier terminates, the transported materials, which have been gathered from a *large area,* are thrown down over a *small area* in the form of crescentic mounds of rough debris, known as **terminal moraines.** The finer mud and sand are carried away by the river which flows from the end of the glacier, and deposited elsewhere.

If the climate of a glacier region becomes warmer, so that the glaciers gradually melt, some of the large stones borne upon its surface may get stranded on the side of the valley as the level of the ice sinks, forming the *perched blocks* or *erratics*, which, together with the occurrence of other marks of glacial action (such as moraine heaps, polished and scratched surfaces, etc.), enable us to infer the former existence of glaciers in regions where the ice has long since disappeared. For example, upon the slopes of the Jura mountains, which are composed mainly of limestone, there are scattered erratics of granite, gneiss, and other rocks, which can be traced to their source in the Alps 50 miles away. It was formerly imagined that a great flood of water had carried them across the broad central strath of Switzerland, or that they had been conveyed by floating icebergs, but these theories would not account for the *definite arrangement of the deposits, in the order which ought to prevail* (as was first shown by Guyot) *if they had constituted the moraines of ancient glaciers* much larger than those now existing in the Alps. Fig. 54 represents one of the perched blocks of the extinct glacier of the Rhone.

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[1] See *Nature.* Dec. 27, 1888. Vol. xxxix.

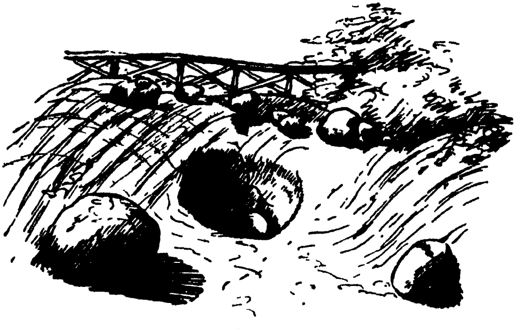

Fig. 53.

In the glacier-garden of Lucerne (Fig. 53) we have (to take one example out of many) in the polished and scratched surfaces of the rock, and in the deep pot-holes formed by the swirl of the waters falling down some crevasse, other evidences of the former great extension of the Swiss glaciers. Similar indications have been found in Scotland, Wales, and the North of England (as well as in other northern countries); all this proves conclusively that there was a period (often known as the *Great Ice Age)* when glaciers existed in these areas. The moraine heaps and perched blocks of the Pass of Llanberis, and the domes of polished rock in Borrodale and other parts of the Lake District, are well known instances of these memorials of the Ice Age in Britain. Many geologists maintain that not merely local glaciers, but a huge **ice sheet**, such as now covers nearly the whole of Greenland, once extended over a large part of this country, and that the tough, unstratified clay (known as "till" or "boulder-clay"), containing smooth and striated stones scattered confusedly through it, was formed as a *ground moraine* of this ice-sheet.[1]

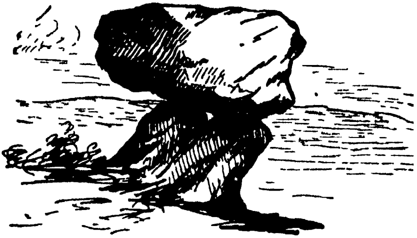

Fig 54

4. **The Sea as a Geological Agent.**—The EROSIVE work of the sea is mainly performed by means of its *waves*, aided by the loose detritus (largely furnished by subaerial denudation), which is made use of as a sort of artillery to batter down portions of the cliffs. The annals of many places tell us how the ocean is thus making slow but sure inroads upon our coasts: many towns and villages on the east coast, for example, such as Ravenspur (where Bolingbroke landed in

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[1] See a suggestive paper, by Mr. J. E. Marr, on *The Work of Ice-sheets* in *Geological Magazine*, April, 1887.

1399), in Yorkshire, and the old town of Cromer, in Norfolk, have long since disappeared beneath the waters of the German Ocean.

The RATE at which the cliffs recede depends upon (1) *the energy with which the waves attack the land*, and (2) *the resistance which the land opposes to the waves.* The form of a COAST LINE is to a great extent due to the variation of this rate at different places, the harder rocks standing out as promontories, the softer being worn into bays and coves. The encroachment of the sea upon the land in Britain is greatest on the east coast, because, although the west coast is more exposed to the open sea, the older rocks of much of our western shores are harder and better able to withstand the attacks of the waves. On the south part of the Yorkshire coast there is an average waste of 2¼ yards annually. In some places, as in the Fenland, there is reconstruction of land by the silting up of bays and estuaries: the land thus formed is for the most part low and marshy.

The sea acts as an agent of TRANSPORT by its waves, tides, and currents. The coarse detritus is deposited near the shore, while the finer material is carried out to sea, not often, however, to any very great distance. The DEPOSITS found in the sea may therefore be classed as (i.) **terrigenous and shore deposits** (sands, gravels, and muds), formed both in shallow and in deep water, near the shores of continents, seldom extending beyond two or three hundred miles, (ii.) **Pelagic or oceanic deposits**, mainly of organic origin, formed in deep water remote from land. The chief varieties of these deep sea deposits are—

(*a*) *Globigerina ooze* (300 to 2250 fathoms), consisting almost entirely of the shells of minute calcareous organisms, such as the globigerina and other foraminifera (fig. 55), which live in countless numbers in the surface waters, the shells sinking to the bottom when the animals die.

(*b*) *Red clay* (below 2250 fathoms), probably in part of volcanic origin, and partly representing the insoluble residue of organisms, after the carbonate of lime has been removed by solution before they can reach such great depths.

(*c*) *Radiolarian ooze*, in the deepest parts of the Pacific, partially composed of the siliceous skeletons of radiolaria. (Fig. 56.)

(*a*) In Polar regions deposits of *siliceous diatoms* largely replace the globigerina ooze of warmer areas.

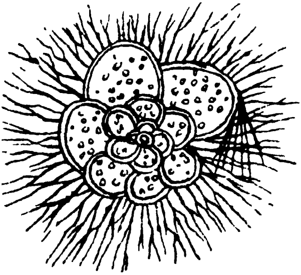

Fig. 55.

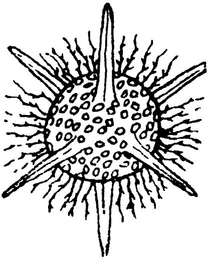

Fig. 56.

5. **Classification of the Aqueous Rocks.**—It has been shewn, in the first section of this chapter, that the aqueous rocks may be classified according to their ORIGIN, some (such as sandstone and gravel) having been formed by the *mechanical* action of moving water; others (as coral limestone, etc.) by the action of *organisms*; others (as tufa) by *chemical* precipitation. We may also group them according to their COMPOSITION, some being mainly composed of *silceous*, some of *calcareous*, and others of *argillaceous* materials. The following table shows the general character of the more common stratified rocks. The classification of strata according to their relative AGE will be considered in a later section.

References.—Green's *Physical Geology*, ch. iii. and iv., *The Earth's History* (Murray), by Dr. R. D. Roberts; *The Cruise of the Challenger*, by Dr. J. Murray (Manchester Science Lectures, 9th Series), and the larger *Challenger* Reports, especially, "Report on the Deep Sea Deposits," by Murray and Renard (Eyre & Spottiswoode).

Siliceous Rocks.	Argillaceous (or Clayey) Rocks.	Calcareous Rocks (largely composed of Carbonate of Lime).	Carbonaceous Rocks.
These rocks are mainly clastic or fragmental (mechanically formed).		These rocks are generally organically (or in some cases chemically) formed.	
Shingle and **Gravel**: more or less rounded pebbles, unconsolidated. **Sand**: small grains mainly of Quartz, but also containing bits of felspar, mica, magnetite, etc. The grains are most rounded in wind-blown desert sands. **Conglomerate**: consolidated shingle or gravel. Quartzose pebbles are the commonest, but conglomerate may be composed of all kinds of materials. **Breccia**: angular fragments cemented together. **Sandstone**: consolidated sand; the colour usually depends upon the kind of cementing material, which may be ferruginous (iron oxides), giving red and brown sandstones; calcareous, forming soft sandstones; and siliceous forming strong light-coloured sandstones. **Grit**: coarse angular sandstone. **Tripoli**: or Diatom Earth, a soft light material, looking like clay, composed of siliceous diatoms, etc. **Flint** and **Chert**: siliceous rocks, which appear to be mainly of organic origin, formed from siliceous sponges, etc. **Siliceous Sinter**: a chemical deposit from geysers and hot springs.	**Mud** and **Silt**: impure unconsolidated argillaceous deposits. **Clay**: compact fine grained plastic rock, white when pure, but usually coloured by iron oxides, etc. **Kaolin**: pure white China clay, resulting from the decomposition of the felspar of granitic rocks. **Shale**: hardened laminated clay. **Marl**: calcareous clay, effervesces with acid. **Fire-clay**: contains much sand. **Slate**: is often an altered argillaceous rock (See Section on Metamorphic Rocks.) [**Blue and Grey Clays, etc.**, often become red or brown by *weathering*, owing to the oxidation of *ferrous* into *ferric* oxide. v. p. 93.]	**Limestone**: term applied to any rock essentially composed of carbonate of lime; may be scratched with a knife, and effervesces with acid. Impure varieties are distinguished as siliceous, argillaceous, etc. **Chalk**: soft white earthy limestone. **Oolite**: composed of small grains like the roe of a fish. **Pisolite**: composed of larger grains. **Hydraulic Limestone**: contains sand and clay. **Cornstone**: a variety of siliceous limestone. **Dolomite** or **Magnesian Limestone**: contains carbonate of magnesia, and is harder and less soluble in acid than ordinary limestone. **Travertine** or **Tufa**: carbonate of lime precipitated from solution.	**Peat**: a modern deposit of compressed partly decomposed plants, especially bog mosses. **Lignite**: more compressed and chemically changed. **Cannel Coal**: compact, with shiny lustre, and conchoidal fracture; easily ignited. **Jet**: a variety of cannel. **Ordinary Coal**: jet black, brittle; usually breaks into cubes. Formed of decomposed mineralised vegetable matter. Contains 75 to 80 per cent. of carbon. **Anthracite** or **Stone Coal**: hard, heavy (sp. gr. 1·4); glossy lustre, does not soil the fingers; a sort of natural coke, or coal from which the hydrogen and oxygen have been expelled, leaving 90 per cent. or more of carbon. (The steam coals of commerce represent a stage between ordinary bituminous caking coals and anthracite.) **Graphite** or **Plumbago**: popularly known as Black Lead. Consists of carbon, with about 5 per cent. of impurities.

Section III.—Volcanoes and the Igneous Rocks.

1. **Volcanic Phenomena.** — A VOLCANO is, primarily, a vent, or assemblage of vents, communicating with some highly heated portion of the earth's crust, through which materials in a molten or fragmentary condition have been ejected to the surface. These materials have usually accumulated to form a more or less conical hill or mountain termed a *volcanic cone*, at or near the top of which is an orifice termed the *crater* ("cup"). The ACTIVITY of a volcano manifests itself in the emission of various heated materials either from the crater or from a fissure opening in the side of the cone. This activity may be either constant or intermittent. Stromboli, in the Lipari Isles, appears to have been in a perpetual state of eruption ever since the earliest historical times, and, as the action in this case is not usually very violent or dangerous, the volcano has been often visited and the phenomena of its eruptions carefully observed. Looking down into the crater of this volcano (which is situated 1000 feet below the apex of the cone) one sees that the black slaggy bottom of the orifice is traversed by fissures, and within some of the larger of these openings a viscid material can be observed in violent motion. From time to time the movement increases until a great bubble or blister, is formed, which suddenly bursts with the production of an explosive outrush of steam, together with slaggy fragments which are hurled some hundreds of feet above the crater, and often fall on to the slopes of the cone. Many of these fragments, when examined, are found to be glowing and in a pasty condition. Sometimes, as in June, 1891, there follows an outflow of molten *lava*, which streams down the mountain sides into the sea. The steam, condensing in globular masses, forms a cloud canopy above the mountain, which varies in appearance according to atmospheric con-

ditions, and this canopy reflects the glow of the incandescent lava at the bottom of the crater (just as the glow of the furnace is reflected in the steam cloud issuing from a locomotive engine), thus giving rise to the periodic illumination of the cloud, often erroneously attributed to actual flames, which has earned for the volcano the title of the "Lighthouse of the Mediterranean."

In the more striking but less frequent eruptions of such volcanoes as Vesuvius or Etna we have practically the same series of phenomena on a much grander scale. Thus, in the eruption of April, 1872, of which an account has been given by Palmieri, the sides of the mountain were rent by fissures, from which, as well as from the crater, enormous volumes of steam were ejected in a series of explosive bursts, together with great quantities of solid material; the vapours and rock fragments being thrown to a height of nearly four miles above the crater. At three principal, and many minor vents, the lava rushed out and flowed down the mountain sides, destroying villages and houses; great volumes of steam escaped from the congealing lava and forced it into great bubbles and blisters like miniature volcanic cones. Within the column of ascending dust and vapour, electricity was generated, which produced the effects of thunder and lightning, while the condensation of the enormous volumes of steam led to the production of torrents of rain.

The enormous energy of volcanic action manifests itself most strikingly in the great paroxysmal eruptions which usually follow long periods of quiescence. Perhaps the most remarkable of all recorded eruptions was that of the Island of Krakatoa, in the Sunda Strait, in 1883, which occurred after a repose of 200 years. The eruption, preceded by earthquakes in 1880, began on May 20th, and the noise of the explosions was heard in Batavia, 100 miles away, while the volcanic dust was carried to a distance of 300 miles. The activity continued until the end of August, when it culminated in a series of tremendous explosions, by which the island was largely destroyed, the contour of the sea-bed entirely changed, and the Sunda Strait rendered for a time impassable. Enormous *sea waves* swept over the coasts of Java and Sumatra, producing great destruction and loss of life, and the greatest of these waves appear to have been observed over half the globe, affecting even the tide gauges of our own coasts. The *air waves* produced by the sudden expansion of the erupting gases affected the barometer all over the globe, and seem to have even travelled seven times backwards and forwards round the world (completing the circuit of the globe in 36 hours), while the actual *sounds* were heard over an area of $\frac{1}{15}$ of the earth's surface, nearly equal to the area of Europe and Africa put together. The cloud of volcanic dust, consisting of fine threads and plates of glassy lava, shot up to a visible height, estimated at from 12 to 23 miles, seems to have spread through the upper regions of the air, remaining suspended for months and even years, causing the peculiar red sunsets and other remarkable atmospheric phenomena seen shortly after the eruption in the equatorial regions, and, subsequently, observed all over the world.

2. **Volcanic Products.**—It has been estimated that $\frac{999}{1000}$ of the GASEOUS PRODUCTS of an eruption consist of steam; but other gases, such as hydrochloric acid, sulphurous acid, sulphuretted hydrogen, etc., are also generated, and by their action upon each other and upon the constituents of rocks with which they come in contact, produce deposits of sulphur, specular iron, gypsum, etc. Some of the gases emitted are combustible, and being ignited by the heat, burn with feebly luminous flames; such flames do not, however, as popularly imagined, form a conspicuous feature of volcanic eruptions. The molten rock or LAVA, already mentioned, is at a white heat when first issuing from the volcano, but it soon cools upon the surface and assumes a

cindery aspect, while often remaining red hot for months or years below. Some lava streams are of great size, as that of Skaptar Yokull in Iceland (1783), estimated by Bischoff to have surpassed in magnitude the bulk of Mont Blanc. In many cases they flow with great rapidity; in the eruption of Vesuvius in 1805, for instance, a stream of lava is said to have rushed down a space of 3½ miles in 4 minutes. Besides the surface lava streams, much molten rock is injected into cracks and fissures, forming more or less vertical **dykes**, horizontal **sheets or sills**, and finer branching **veins.** It is also (as already mentioned) discharged in the form of slaggy fragments of all shapes and sizes, the larger pieces being known as *bombs* and *scoriae*, and the smaller as *lapilli* and *dust.* The accumulations of these fragmentary materials constitute the layers of coarse volcanic **breccias** and **conglomerates**, and fine compact **tuffs** and ashes which, alternating with the lava streams, build up the normal type of volcanic cone (Fig. 57). In some cases cones are formed consisting entirely of *fragmentary* materials (as Mont Nuovo), and in others (as in the volcanoes of Hawaii) enormous flattened cones are built up of *fluid lava* only. It has been suggested that in former times great flows of basaltic lava have been forced from long fissures in the earth's crust, without the formation of any actual cones,

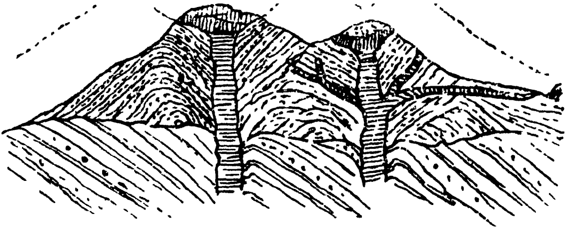

Fig. 57.

producing the extensive, practically horizontal, deposits of Colorado, Abyssinia, the Deccan and other districts. (*Cf.* p. 173.)

3. **Proofs of Volcanic Action in Past Geological Times.**—Whenever a volcano ceases to grow up, it begins to be worn down and destroyed by denuding agents. It is by the natural *dissection* of a volcano, due to prolonged erosion, that we are able to discover something of its INTERNAL STRUCTURE as shown in Fig. 57. In the extinct craters of the Eifel, Auvergne, etc., many of which now form lakes (as shown in Fig. 58, which represents the crater lake known as the Weinfelder Maar in the German Eifel), we have examples of volcanoes in which the destruction of the cones has not proceeded very far, while in the lava flows and ash beds of Snowdon and the Lake district, and the basalts of the North of Ireland, etc. (already referred to), we have instances of later stages in the process of decay. In some cases the original cones have been completely destroyed, and it is impossible to fix their exact sites; in others, as in many of the dome-shaped hills of Central Scotland (Largo Law, N. Berwick Law, etc.), we have the filled up central pipes or funnels (*necks*) of actual cones, mere worn stumps of once considerable mountains.

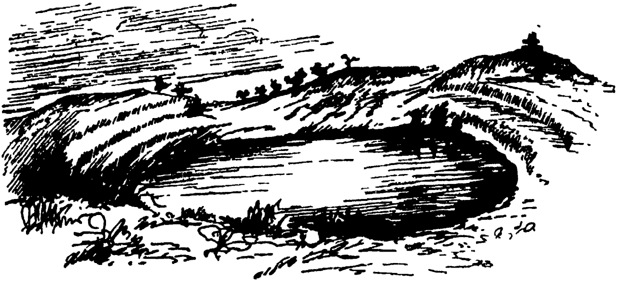

Fig. 58.

4. **Classification of the Igneous Rocks.**—The crystal-

	ORTHOCLASE the Predominant Felspar.		PLAGIOCLASE FELSPAR Predominant.			Little or no Felspar.	
	With Free Quartz.	Little or no Free Quartz.	With Free Quartz. [Felspar commonly Oligoclase.]	With Hornblende. [Felspar commonly Oligoclase.]	With Augite. [Felspar commonly Labradorite.]	With Nepheline or Leucite.	With Olivine.
I. WHOLLY CRYSTALLINE Type. (*a*) *Coarsely Granular.*	**Granite**: composed of Orthoclase Felspar, Quartz, and Mica, often with Hornblende, and usually with some Plagioclase.	**Syenite**: distinguished from granite by the more or less complete absence of free Quartz. Consists essentially of Orthoclase and Hornblende.	**Quartz Diorite** (*Tonalite*). includes many rocks commonly called granite.	**Diorite**: composed of Plagioclase and Hornblende, and often Mica. Usually greenish in colour.	**Gabbro**: plagioclase and diallage (variety of augite). *Olivine Gabbro*: the same with olivine.	*Nepheline Gabbros* and *Dolerites* in which the felspar is largely replaced by Nepheline.	**Peridotite** group. (*Picrite Olivi Rock, etc.*) These rocks o ten alter into *se pentines.*
(*b*) *Finely Granular.*	**Eurite** (*Quartz-Felsite*): a fine grained rock, essentially composed of Quartz and Orthoclase.	Some **Felsites.**	**Quartz Aphanite**: includes the more compact fine-grained varieties.	**Aphanite**: (porphyrite of some authors).	**Dolerite**: dark granular rock. Usually weathering brown. *Olivine Dolerite.*		
II. PARTLY CRYSTALLINE and GLASSY Representatives.	**Rhyolite** (*Quartz Trachyte*): often shows banded and sphaerulitic structures. Many rhyolites were originally wholly glassy rocks, like obsidian, which have become "devitrified" by the gradual formation of crystallites and crystals.	**Trachyte**: composed of glassy felspar (sanidine), with some plagioclase, and usually hornblende or augite. Large porphyritic sanidine crystals are frequent. Colour usually whitish. **Phonolite**: a trachyte containing Leucite or Nepheline.	**Quartz Andesite** (*Dacite*): distinguished from Quartz Trachyte by the absence of Orthoclase.	**Hornblende Andesite**: distinguished from Trachyte by the absence of Orthoclase.	**Augite Andesite**: distinguished from Basalt by the absence of olivine. **Olivine Basalt**: usually black compact heavy rock. Composed of plagioclase, augite, and olivine. *Tachylite* or *Basalt Glass*: is distinguished from Obsidian by being darker, more opaque, and more easily fusible. It is sometimes found as a selvage to basalt dykes.	*Nepheline* and *Leucite Basalt.* (The common lava of Vesuvius is a leucite basalt.) *Nephelinite* and *Leucitite*, felspar entirely absent.	*Limburgit* mainly compo ed of olivi and augite.
	Pitchstone and *Obsidian* are highly glassy forms. Some varieties resemble green bottle-glass. Ordinary *Pumice* is a glassy lava, with numerous steam vesicles.		Andesites in which the felspar is partly replaced by nepheline, are sometimes termed *Tephrites.*				

line rocks produced in connection with volcanoes, consist of a mixture of various minerals, chiefly *Felspar*, *Quartz*, *Mica*, *Hornblende*, *Augite*, and *Olivine*. Their CHEMICAL COMPOSITION depends upon the relative abundance of the different minerals: those, like granite, largely composed of orthoclase felspar and quartz, contain over 66 per cent. of silica, and are termed **acidic**; those, like basalt, composed largely of poorly-silicated felspars with no free quartz, have a low percentage of silica (below 55 per cent) and are termed **basic.** Between these two extremes comes an *intermediate* class (with an average of about 58 per cent. of silica). TEXTURE, as already noted, stands in intimate relation to conditions of consolidation, as well as to composition, and is useful in forming subdivisions. Those coarsely crystalline rocks, like granite, which have consolidated at great depths, we term **plutonic**, in contra-distinction to the truly **volcanic** lavas which have solidified at or near the surface. The table (p. 178) shows the mineralogical composition and character of some of the commoner massive Igneous Rocks. The different varieties, however, pass into one another by insensible gradations; there is, moreover, a great want of uniformity in the nomenclature of these rocks, the same term being often used in different senses by different writers.

5. **Distribution of Volcanoes.**—There appear to be but few parts of the world where volcanoes have not at some time or other contributed to the formation of the rock masses of which the earth's crust is composed, but the volcanic activity seems to have shifted again and again from one part of the earth's surface to another. The existing active volcanoes of the world are, for the most part, *arranged in lines* running along the mountain chains bordering the continental areas. Thus the Pacific Ocean is almost completely encircled by a belt of active volcanoes. Very few volcanoes occur at any great distance from the sea.

6. **Probable Causes of Volcanic Action.**—*Observations in deep mines and wells* show that below a depth of about 50 feet ("stratum of invariable temperature") the temperature of rocks is independent of the seasons, and increases with the depth, at an average rate of about 1° F. for every 60 feet *Hot springs* occur in localities far removed from present volcanic action, and some are probably hot in consequence of the depth from which they come. From such facts as these we are led to believe that the earth consists of a *cool envelope surrounding a heated interior*, which possesses a high temperature, independently of heat derived from external sources. A consideration of the *shape of the earth*, as well as of the relation of the earth to other members of the solar system (see chap. vi.), tends to show that it was once molten throughout, and is now cooling down; though whether any considerable portion of the interior is still in a molten state is an open question.

Now, a cooling body is, in nearly all cases, a contracting body, and this contraction on cooling would give a *general* explanation of the causes both of volcanic action, and of those earth movements (see section iv.) by which the strata have been bent and fractured; the cool solidified crust having continually undergone a process of *crumpling* in accommodating itself to the more rapidly shrinking hotter nucleus within. As to the precise manner, however, in which the outflow of lava in volcanoes has taken place, there is much difference of opinion. Mr. Mallet maintained that the heat produced in the *crushing* of surface rocks, caused by contraction, would be sufficient to liquefy some of the more fusible rocks, and thus to form subterranean cavities full of molten material; others hold that the materials kept solid by pressure become liquefied when the pressure is from time to time removed by the folding and crumpling of the crust; this liquefied lava material may then be squeezed up into fissures by the weight of the subsiding crust in adjoining areas. The fact that nearly all active volcanoes occur near the sea, together with the presence of water in ejected lavas, seems to suggest some necessary connection between the presence of water and volcanic eruptions, and as it is probable that water can percolate through pores of rock impervious to steam, it has been maintained that the ascent of lava to the surface is determined by the pressure of steam formed from water which has thus penetrated to the reservoirs of molten material. In some cases, as in the Hawaian volcanoes, the amount of steam which escapes from the lava seems hardly sufficient to warrant the conclusion that it has been an essential factor in forcing the lava to the surface. The *violence* of an eruption may, however, largely depend upon the more or less explosive escape of steam imprisoned or *occluded* in the molten lava.

References.—Prof. J. W. Judd, *Volcanoes* (Int. Science Series); Prof. E. Hull, *Volcanoes, Past and Present* (Contemp. Sc. Series), and relevant portions of Sir A. Geikie's *Text Book of Geology*; Prof. Grenville Cole's *Aids in Practical Geology*. See also the elaborate report on Krakatoa, published by the Royal Society.

Section IV.—Earth Movements. The Metamorphic Rocks.

1. **Earthquakes.**—If one end of a long heavy block of wood or metal, resting on the ground, be struck with a hammer, it will be observed that while no movement of the body as a whole is produced, yet a vibratory motion of the molecules is transmitted with great rapidity through the block, sufficient to cause a small body, such as a suspended bullet or button resting against its far end, to be thrown off. An EARTHQUAKE is produced by a similar transmission of *waves of elastic compression* rapidly traversing part of the earth's crust. Suppose a sudden blow or jar to be pro-

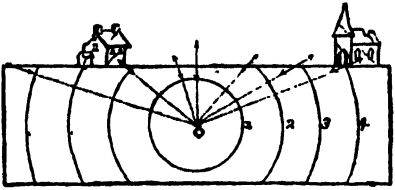

Fig. 59.

duced at o, Fig. 59, then a series of waves will start from o, and spread out more or less spherically, as shown by the numbers 1, 2, 3; over the centre of origin, or **focus**, the shock will be felt at the surface as a vertical up and down movement. Receding from this **epicentrum**, the movement becomes more and more oblique, as shown by the arrows, until it ultimately dies away. The *line of emergence* of the wave at any place will be, on the whole, *perpendicular to the fractures* produced in buildings. This line intersects the **seismic vertical** at the focus, the depth of which may thus be determined. Earthquake centres have in this way been found to occur at from 5 to 35 miles below the earth's surface. Earthquake waves are not really spherical, because they travel at unequal rates through rocks of different density. Experiments have shown that elastic waves travel about two miles per second through hard rocks, but only half as fast through soft sand. Besides the wave of shock transmitted through the solid crust of the earth, waves are also propagated *through the air* producing the characteristic sounds of rolling waggons, or distant thunder, and also, in many cases, *through the sea*, as in the great Lisbon earthquake of 1755, when the Tagus rose 40 feet above the ordinary high water mark. Earthquakes occur constantly in volcanic regions, and the seismic centre appears to be sometimes coincident with the volcanic centre; they also occur in non-volcanic areas. Probably, at least, one earthquake occurs every day at some part of the earth's surface. The origin of the explosion or sudden blow from which an earthquake is propagated can only be conjectured. Perhaps the snap and jar caused by the sudden dislocation of deep-seated rocks is the most frequent cause. *Permanent changes of level* sometimes *accompany* earthquakes, but are not, strictly speaking, produced by them. The coast of Chili, for example, was raised 3-4 feet during the earthquake of November 1822.

2. **Slow Upheaval and Depression.**—Apart from these comparatively sudden changes of level, slow movements of the earth's surface are continually taking place in different parts of the world. A remarkable proof of such movements having occurred within historical times is afforded by the ruins of the so-called Temple of Jupiter Serapis, near Puzzuoli, a full description of which will be found in Lyell's *Principles of Geology*. The most striking feature of these ruins is a row of three marble pillars, about 40 feet high, which were formerly buried to a height of about 12 feet in soft tuff. Above this height occurs a zone of about 9 feet, where the marble is perforated by marine boring shells, proving a submergence for a long period of time beneath the sea, as well as a subsequent re-elevation. Other instances, discussed by Lyell, are those of the shores of the Baltic, where there seems to be a gradual rise of the land over a considerable area, at a rate varying from 5 feet in a century, near the North Cape, to only a few inches south of Stockholm; and of the coast of Greenland, where it is known that a tranquil depression of land is taking place over a space more than 600 miles long from north to south. Ancient buildings have been submerged, and experience has taught the Greenlander never to build his hut near the water's edge. In the *raised beaches* and *old sea caves*, far above high water mark, which are found at various parts of our own coasts, we have proofs of such movements of elevation in geologically recent times, while the fact that rocks, which were once deposited in the sea, are now far inland and even form lofty mountains, shows that elevation to a far greater extent has taken place in former ages.[1]

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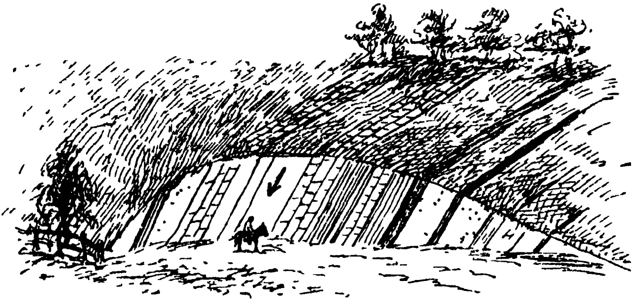
[1] It is quite possible, however, that some of these phenomena may

3. **Effects of Earth Movements on Rock Masses.**—The stratified rocks now visible at the earth's surface are seldom in their original position. The earth movements to which they owe their elevation have also caused them to become tilted, contorted, or fractured. When the strata are not horizontal the *inclination* of the beds with a horizontal plane is termed the **dip**, and the *intersection* of the beds with a horizontal plane is termed the **strike** (German, *streichen*—to extend). The strike may also be defined as the *line of outcrop on a level surface*, since it represents the direction in which a stratum *extends* across a flat country, as shown in Fig. 60. It will be seen that the direction of strike is *at right angles* to the direction of dip, so that if the strata dip to the east or to the west, they strike in a N. and S. direction. It was first shown by William Smith in the early part of this century that the *general arrangement* of the rock-beds, which form the greater part of England, is that of a series of layers or strata dipping to the S.E., and, therefore, striking from N.E. to S.W. (Fig. 61).



(The arrow shows direction of *d*

This inclination or dip of strata results from the undulations or *folds* into which they have been thrown, the upper

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be due to changes of the sea level itself, and not to movements of the lithosphere. *See* Suess, *Das Antlitz der Erde.*

portions of the folds having been removed by the processes of denudation. When these curves are only a few yards across they are commonly called contortions, when on a larger scale they are known as **anticlinal** and **synclinal** curves (Figs. 61 and 62). In an anticline the convex side of the curve is uppermost, as in an arch, while a syncline has its concave side upwards, as in a trough. In some cases earth movements have caused the rocks to be fractured or broken through, the fracture being accompanied by a shift of the beds as shown in Fig. 44. Such a shift, sometimes perpendicular, but more generally inclined at various angles to the horizon, is termed a **fault**. Faults vary in all possible ways, the amount of shift or *throw* being sometimes only a few inches, and in other cases hundreds

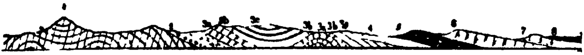

Fig. 61.—Diagrammatic section from Snowdon to the North Sea (1) Cambrian and Silurian, (2) Old Red Sandstone, (3a) Carboniferous Limestone, (3b) Millstone Grit, (3c) Coal Measures, (4) Trias, (5) Lias, (6) Oolites, (7) Chalk, (8) Tertiaries.

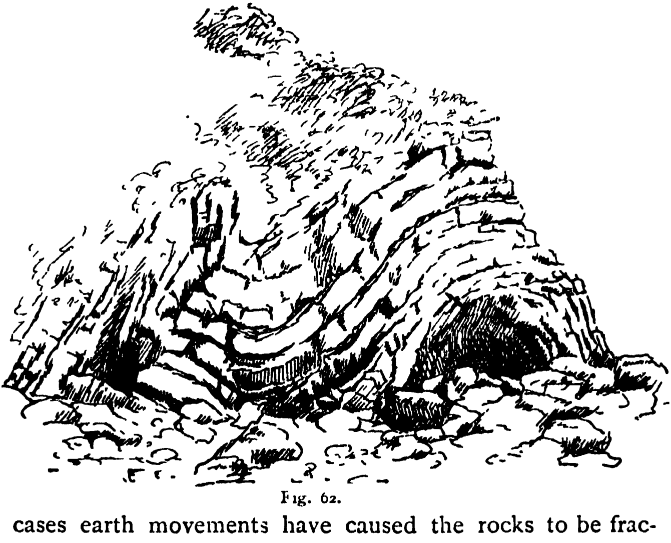

Fig. 62.

of feet; while the line of fault may be only a few yards in length, or extend for many miles. As a general rule, faults *hade* or slope towards the down-throw side, as in Fig. 44. In a *reversed* fault the hade is towards the up-throw side. Inverted anticlinals often pass into these faults. Sometimes (as in the Highlands of Scotland) the dislocations take the form of nearly horizontal **thrust planes** along which lower beds have been pushed (sometimes many miles) upon the surfaces of originally higher strata. The movements which have brought about the folding and fracturing of rock masses have also frequently strained, compressed, and even crushed them so as to lead to the production of various structures not present in the original materials. First we may note the planes of division known as **joints**, which in sedimentary rocks are usually more or less at right angles to the bedding planes. In some cases these joints may be the result of contraction in drying or cooling (as in the prismatic jointing of basalt already noticed), but in other cases, as where hard pebbles are cut through by joints, mere contraction seems hardly sufficient to account for them, and they are probably due to mechanical strain.

The **cleavage planes** along which ordinary roofing slates split, that (as shown in Fig. 63, representing vertically cleaved slates on the coast of Pembrokeshire) do not coincide with planes of bedding, have probably been produced by great *pressure* exerted in a direction perpendicular to the planes of cleavage; for we find that a microscopical examination of cleaved rocks, as well as an inspection of fossils contained in them, shows that they have always been squeezed in this way, while Sorby and Tyndall have shown experimentally that an artificial cleavage can be set up in wax and other substances by subjecting

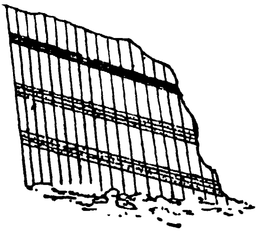

Fig. 63.

them to great pressure. This *rock cleavage*, produced in fine grained materials, such as mud and volcanic ashes, by pressure, must not be confounded with the *mineral cleavage* mentioned on p. 73, nor with the *lamination* of shales, due to successive layers of deposition. The term **slate** (sometimes loosely applied to these laminated beds) should be restricted to cleaved rocks. In some cases, especially in violently contorted mountain districts, such as the Alps and the Highlands of Scotland, the earth movements have so crushed, altered, and deformed the rocks, as to largely obliterate their original characters and convert them into **foliated** rocks, their component minerals being re-arranged in lenticular crystalline layers, or *folia*. The term **metamorphism** is applied to such extreme cases of alteration, and the resulting rocks are termed metamorphic.

4. **The Metamorphic Rocks.**—The alteration of rock masses by the intrusion of igneous rocks is termed *pyro* or *contact metamorphism*. By its action clays and shales are converted into pale flinty rocks known as **porcellanites**, or into darker **Lydian stones**; sandstone is altered into **quartzite**, a hard compact rock with lustrous fracture, limestone into crystalline **marble**, and in extreme cases ordinary sediments into crystalline *foliated* rocks. Quartzites may also be formed by the action of infiltrating water upon sandstones *(hydro metamorphism)*, and by the same agency many igneous rocks become much changed, olivine rocks, for example, being converted into **serpentine**, and vesicular lavas into **amygdaloidal rocks**, so called from their resemblance to almond toffee. The distinctly foliated rocks known as schists and gneisses appear to have been mainly produced by the heat and crushing caused by earth movements *(dynamo or regional metamorphism)*. Some have resulted from the deformation of igneous rocks, while others seem to be altered sediments. Thus granite becomes altered into foliated **gneiss**, a coarsely granular rock in which the constituent

minerals have become re-crystallised or re-arranged in more or less definite layers. Finer foliated rocks containing little or no felspar are included under the term **schist**, of which *mica schist*, composed mainly of mica and quartz, is the commonest variety. The origin of some of the crystalline schists has been much debated, and is still among the unsolved problems of geology.

References.—Green's *Physical Geology*, ch. vii.; Geikie's *Text-Book of Geology*, book iii. part i.; Page and Lapworth, *Introductory Text-Book of Geology*.
Milne, *Earthquakes and other Earth Movements*. (Kegan Paul.)

Section V.—The Records of the Rocks.

1. **Determination of the Relative Age of Rocks.**—From the manner in which the stratified rocks were formed it is obvious that when we see one bed resting upon another the upper one must in general be the newer of the two. Now it has already been mentioned that we have in this country, as shown by Wm. Smith, a clear succession of beds dipping for the most part towards the south east, the older rocks thus come to the surface to the W. and N. as shown in Fig. 61, and form a sort of uneven floor upon which successive deposits of newer strata have been laid. Borings for deep wells in the east of England have actually proved the existence below London of the old rocks which only crop out far to the west. Wm. Smith further showed that various groups of beds were distinguished by the special character of their fossil remains; in fact, we find a *definite order in the appearance of life forms*, and thus having once determined the relative ages of the strata in one district by their *superposition*, we can afterwards make use of the fossils for correlating the beds of different districts or countries.

2. **Conformable and Unconformable Strata.**—When one series of rocks has been laid down continuously and withou

disturbance upon another series they are said to be *conformable*. When one set of beds has been largely denuded before the deposition of another series the upper set of beds is said to rest *unconformably* upon the lower; thus in Fig. 64, representing a section on the coast of Barry Island, we have an upper set of beds (*b*) known as the *dolomitic conglomerate*, resting upon the upturned denuded edges of the *carboniferous limestone* beds (*a*). The conglomerate represents an old beach deposit, made up of pebbles and boulders of the limestone, just like the modern pebble beach (*c*) now in process of formation.

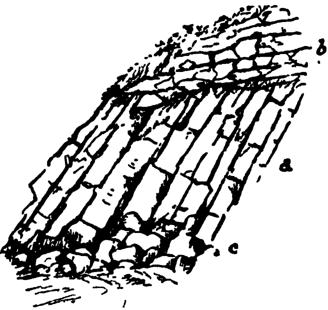

Fig. 64.

3. **Classification of Strata.**— In the arrangement of stratified rocks into divisions according to their relative age, we seek to class together the strata deposited during the same set of geological conditions. Great unconformities indicate a change in the physical conditions, and are therefore of much use in classifying the strata into *systems*. Similar smaller breaks help to form minor sub-divisions (*series* and *stages*). The classification of rocks into systems by unconformities can, however, only be a true and natural one for a limited area, for it is clear that while there was elevation and denudation in one area, sediments must have been thereby formed in adjoining areas. Hence no complete section is found in any one region. The term **formation** is frequently applied to a set of beds having certain common lithological (stony) characters. Thus we speak of the *chalk formation*, the *old red sandstone formation*. The word **zone** is used to indicate the presence of some special characteristic fossil, and it may include a whole formation, or only a very

TABLE OF BRITISH STRATA.

Tertiary or Cainozoic (recent life) Rocks, containing fossils not very different from existing species.	**Recent.**		Separated by some geologists from the Tertiary, as *Quaternary* o Tertiary.
	Pleistocene. (Most recent.)		Includes all superficial formations, such as the alluvial deposits of n rivers and lakes, sand dunes, etc., as well as the moraine debris, b clay, etc., due to ice action.
	Pliocene. (More recent.)		Local shelly deposits ("*crags*" occurring in the East of England. ness, 120 feet.
	Miocene. (Less recent.)		Not developed in Britain.
	Oligocene. (Few recent.)		Occurs in Hampshire and the Isle of Wight. These beds were fo classed as Upper Eocene. About 400 feet.
	Eocene. (Dawn of the recent.)		A series of marine and estuarine beds, often very rich in fossils, fo S.E. England *(London Basin)*, and in Hampshire and Isle of *(Hants Basin)*. About 1500 feet.
			[The names Eocene, etc. (Greek, *Kainos*—recent), relate to the propo recent to extinct forms of fossil shells.]
Secondary or Mesozoic (middle life) Rocks. General character of life forms not unlike existing ones, but species altogether different.	**Cretaceous.** (*Creta*-chalk.)	Upper.	*Chalk* and *Chalk Marl:* the upper part banded with la flint. *Upper Greensand* and *Gault* (a stiff blue clay). 1500 feet.
		Lower. (Neocomian)	*Lower Greensand* (marine sands and ironstones). 55c *Wealden* (estuarine), including Weald clay and H sand-beds. 1800 feet. Partly represented by *Speeton clays* of Yorkshire.
	Jurassic. (From Jura mountains.)	*Oolites.* (Roe-stone.)	Including Upper or Portland (partly fresh-water); Mi Oxford and Lower or Bath Oolites. About 2500 fe
		Lias. (Layers.)	Includes two thick beds of clay, separated by a middl stone. Total, 1500 feet. These beds stretch in an lar band across England from Dorsetshire to Whit
		Rhaetic. (From Rhaetian Alps.)	A thin series of shales and marls with clayey lim 50 to 100 feet Sometimes included in Trias.
	Triassic. (Threefold)		In some localities these beds appear to form one system, for which th *New Red Sandstone* and *Poikilitic* (variegated) have been used. authors include the Permian in the Palæozoic strata. Permian strata are found in West Midland counties, Lake District, a narrow strip from South Shields to Nottingham. The Trias con sandstones and conglomerates below (Bunter), and red marls wi sum and rock salt above (Keuper). Maximum thickness—P 3000 feet; Trias, about 4000 feet.
	Permian. (From *Perm* in Russia.)		
Primary or Palæozoic (ancient life) Rocks. Fossils mostly very unlike modern life-forms.	**Carboniferous.** (*Carbo*-coal.)		Generally divisible into three series (i.) *Coal Measures*, (ii.) *Millsto* and (iii.) *Carboniferous Limestone* (at the base) The beds var ever, considerably as they are traced across the country. Th about 15,000 feet (2½ miles in South Wales).
	Old Red Sandstone and **Devonian.**		In Wales and Scotland these strata consist of red sandstones, conglo and marls, deposited in fresh water, separable in Scotland into comformable series. (Maximum thickness, over 20,000 feet.) In shire, marine limestones, grits, etc., occur, which seem to have b posited at about the same time (10,000 feet).
	Silurian. (From the *Silures*.)		These beds consist of a lower series of conglomerates, grits, slates, ar stones (*Cambrian* and *Ordovician*), and an upper series of san shales, and limestones (*Silurian)*, often resting unconformably u Lower beds. Total thickness, about 40,000 feet. They occur wall, Wales, Warwickshire, Shropshire, Lake District, etc., Scotland and Ireland. [The Silures were ancient inhabitants of South, and the Ordovices of North Wales.]
	Ordovician. (From the *Ordovices*.)		
	Cambrian. (From *Cambria*, Wales.)		
Archæan (*Arche* beginning), Azoic (lifeless), or Eozoic (dawn of life) Rocks. No undoubted fossils yet found.			Includes all the rocks (mainly schists and gneisses), often term *Cambrian*, whose classification and nomenclature is still ur These rocks probably everywhere underlie the undoubted fos strata, but are mostly hidden from view by later deposits. T exposed over considerable areas in N.W. Scotland.

small part of one; thus the Cambrian beds of this and other countries have been divided into three principal zones by the occurrence of certain genera of the extinct order of *trilobites* (Fig. 65), while the Ordovician and Silurian strata contain a large number of zones marked by the presence of certain species of *graptolites* (Fig. 66).

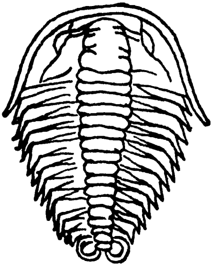

Fig. 65.

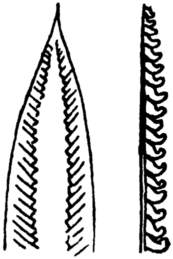

Fig. 66.

The total thickness of the known strata is probably about 100,000 feet (20 miles), of which at least 80,000 belong to the Archæan and Palæozoic divisions. (See table of strata.)

References.—Geikie's *Class Book of Geology*, and the larger *Text-Book*. (Macmillan.)
Woodward's *Geology of England and Wales*. (G. Philip & Son.)

Section VI.—Earth Sculpture.

1. **Continents and Oceans.**—We have seen that the materials of the greater part of the dry land have been laid down as sediments upon the sea-bed, and that their present position is due to earth movements, by which the land has been upheaved. While the land areas, as a whole, owe their existence to *upheaval* of the terrestrial crust, their present *surface contours* are largely due to the action of erosive agencies. Whether the great continents and oceans have always occupied, in the main, their present positions is uncertain. A study of the character and fossil contents of

the deposits which now form the chief stratified rocks seems to indicate that they were laid down in water of no very great depth, and it is possible that, unequal radial contraction of the earth having in very early times marked out the *general* position of the main continental elevations and oceanic depressions, the subsequent crust movements have been chiefly confined to the land areas and sea margins.

2. **Mountain Chains.**—Certain portions of the continents rise to a considerable height, and form long ridges or *mountain chains.* They are formed of rocks that have been subject to great *lateral compression*, by which the strata have been bent and wrinkled into a series of long *folds.* In many cases this folding has produced **inversion** of the beds, as shown in (Fig. 67), representing (after Heim) a section from the Rhine Valley to the Valley of the Sernf, through the Vorab and Bleitstocke, where the older rocks (1) have been bent over so as to rest upon newer beds (2). Contrary to popular belief, the present great mountain ranges are geologically *modern features* of the earth's surface, for the constant wearing down of all raised portions of the crust by erosive agencies has long since levelled the more ancient elevations. Deposits of lower Miocene (or uppermost Eocene) age are found on the Dent du Midi, up to nearly 11,000 feet above sea level, thus showing that the final uplifting of the Alps has taken place since that comparatively recent geological period.

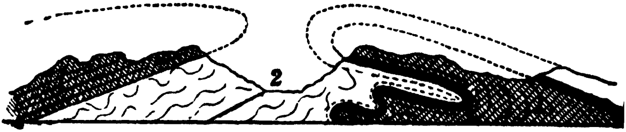

Fig. 67.

3. **General Features of Scenery.**—Just as round our coast lines the harder rocks project *out* into the sea as headlands, while the softer strata have been worn by waves and

currents into bays, so in the interior of the country the more durable materials have been left standing *up* in relief, while softer portions have been worn down by subaerial agencies to form lowlands and plains. The hard rocks which resist the horizontal cutting action of the sea also withstand the cutting down action of rain and rivers. Thus the old Archæan and Palæozoic rocks of Scotland, Wales, and the Lake District—largely composed of igneous and metamorphic rocks—form the most hilly ground, while the soft modern alluvial deposits form flat low-lying plains. The SCOTCH HIGHLANDS may be regarded as a sort of island of ancient crumpled gneisses and schists set in a sea of newer strata. They are not, like the Alps, a true mountain chain, owing its origin mainly to upheaval, but are relics of an old elevated *tableland* which has been *carved out* into its present irregular form by the processes of waste. A great line of fault separates the old rocks of the Highlands from the newer Palæozoic strata of the Lowlands. Here the most striking feature is the abundance of igneous rocks and their effect upon the scenery; the felsites forming usually smooth rounded hills, and the basalts more rugged elevations like Arthur's Seat (near Edinburgh). The great PENNINE CHAIN, or back-bone of Northern England, is formed by a broad irregular anticlinal of Carboniferous rocks, rising from beneath the softer New Red Sandstone strata, that form the plains of Cheshire and of Notts. One of the most marked characteristics of the scenery in the EASTERN AND SOUTHERN PARTS of England is the occurrence of long ridges, or **escarpments**, due to the alternation of gently inclined hard and soft beds. They have a steep or *scarp slope*, usually facing to the N.W., and a more gentle *dip slope* in the opposite direction. These escarpments, due to the action of rain and rivers, are distinguished from cliffs, which owe their origin to marine action, by their being always confined to the boundary of some one hard bed.

The Oolitic escarpment (6 in Fig. 61) may be traced right across England from Dorset, by the Cotswolds, and on in a N.E. direction into Lincolnshire and Yorkshire. The softer clay lands to the east form flat plains, while still further to the east the harder Chalk rises into the scarped ranges of the Chiltern Hills, and the wolds of Lincolnshire and Yorkshire (7, Fig. 61).

Where the strata have been bent into gentle folds we may have two escarpments facing opposite ways, as shown in (Fig. 68), which represents (after Hull) a section across the Cotswold promontory, showing lower Oolitic limestones resting upon Lias clays, which are exposed in the Vale of Moreton by the removal of the overlying beds, whose former extension is indicated by the dotted lines. It will be seen that the original anticlinal elevation, perhaps broken and fissured at the summit, has more readily yielded to erosive agencies, and now forms a valley, while the accompanying synclinal depression, hardened by compression, has better withstood the processes of atmospheric denudation, and now forms a hill. Such "anticlinal valleys" and "synclinal hills" are very common. The basin shape of our principal coal fields, (as shown in Fig. 61), is similarly due to the folding of the carboniferous strata into anticlinals and synclinals, and to the subsequent removal of the upper beds from the summits of the anticlinals.

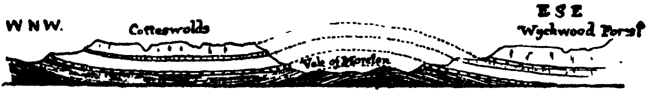

Fig. 68.

References.—For a very interesting discussion of the origin of the larger features of the earth's surface, see the presidential addresses to the *Geological and Geographical* sections of the *British Association*, 1892.

For the effects of denudation, see chap. x. of Green's *Physical Geology;* Ramsay's *Physical Geology and Geography of Great Britain;* and Geikie's *Scenery and Geology of Scotland.*

CHAPTER VI.

THE EVOLUTION OF THE EARTH.

Section I.—The Earth's Place in Nature.

1. **The Solar System.**—We have seen how Copernik assigned to our earth its true place as one of several planets or worlds revolving round the sun. These planets, together with smaller bodies, termed **meteors** (popularly known as falling stars), and **comets** (which very probably consist of swarms of meteoric fragments, illuminated partly by reflected sunlight, partly by electric discharge, and perhaps also by incandescence), constitute a separate group of heavenly bodies termed the *solar system*. The table on pages 198-9 gives some of the important facts with regard to the planets.

Now, it was shown, by Laplace, that since all the planets travel round the sun in the same direction in orbits which are nearly circular, and nearly in the same plane, and since many of them have satellites which travel round them in nearly circular orbits, and (in almost every case) in the same direction (this being also the direction in which both planets and sun rotate on their axes), it is almost certain that all these bodies must have had *a common origin*. If this be so, we should expect that there would be a great similarity in their chemical constitution. Now, in the case of those meteors, which occasionally fall to the earth as *aërolites,* we find that no element unknown on the earth has yet been detected. Many of them consist mainly of *iron* alloyed with *nickel* and some other metals, while others are stony masses resembling, in composition, some of the basic igneous rocks. We have, moreover, as will be seen later, in the spectroscope a means of determining the composition of the sun and stars, which also are thus found to consist largely of known terrestrial elements.

2. **The Distances of the Fixed Stars.**—The method by which the distance of the moon from the earth may be found by determining its *parallax* has already been noticed. In this case the *base line* used is the distance between two points on the earth's surface. With such a base line none of the fixed stars show any apparent change of position whatever, but by using the much longer base line of the *diameter of the earth's orbit* (186 million miles) very careful measurements have shown that some stars do (after correcting for aberration) give a very small parallax, that is to say, *when viewed from opposite points of the earth's orbit, their position on the celestial globe appears to be very slightly shifted.* In the case of the nearest fixed star, known as ALPHA CENTAURI, the amount of parallax thus observed is only $\frac{3}{4}$ of a second of arc, corresponding to a distance of more than 250,000 times the distance of the sun from the earth. This distance is such that light, which travels at the rate of 186,000 miles a second, takes more than four years to travel from Alpha Centauri to the earth. Similarly it takes about 25½ years for light to travel from ARCTURUS, and 42½ to travel from POLARIS to the earth. Most of the stars do not give any measurable parallax, and are, therefore, at vastly greater distances. It can be shewn that the sun, if moved to the distance of Polaris, would not be visible to the naked eye. Hence, it follows that Polaris must be very much brighter, and probably larger, than our sun. Many stars when seen through powerful telescopes are found to be double, that is, to consist of two or more separate stars re-

volving (at any rate in some cases) round their common centre of gravity. Knowing the dimensions of the orbits as well as the distances and periods of revolution of such double stars, their *mass* can be calculated, and in this way it is found that Alpha Centauri has twice the mass of our sun, while other stars have a much greater mass. Such investigations serve to show that the stars are really suns, many of them much larger and brighter than our own (which must thus be regarded as only a star of average size).

3. **The Movement of the Solar System.**—Many of the so-called fixed stars are found by careful observation to have a small motion in the heavens (amounting to 10 seconds of arc in some cases), called their **proper motion.** Sir William Herschel first showed that a part of the proper motion of the stars might be an *apparent* motion, due to an actual motion of the sun and its system in space, at the rate of about 4 miles per second towards the constellation Hercules. The part of the proper motion of the stars, which cannot be accounted for by this movement of the solar system through space, is attributed to movements of the stellar systems themselves. Independent proof of the rapid motion of some of the stars in the line of sight is afforded by the evidence of the spectroscope.

References.—R. A. Gregory, *The Vault of Heaven* (in this series).
Sir R. S. Ball, *Starland* (Cassell & Co.).
Professor S. P. Langley, *The New Astronomy* (Boston : Ticknor & Co.).
Professor S. Newcombe, *Popular Astronomy* (Macmillan).

Section II.—Spectrum Analysis.

1. **The Spectrum.**—When a ray of sunlight enters a darkened room through a hole or slit in a shutter, and falls upon a triangular piece of glass called a **prism,** as diagram-

TABLE

[NOTE.—The relative distances of the planets from the sun (except Neptune) are approximately
52, 100, 196 (*Bode's Law*). These numbers multiplied by 9 give approximately the distances in mi

	MERCURY.	VENUS.	EARTH.	MARS.
Approximate length of DIAMETER in miles	3000	7500	8000	4200
VOLUME compared with Earth (=1)	$\frac{1}{17}$	$\frac{6}{7}$	1	$\frac{1}{7}$
MASS (Earth=1)	$\frac{1}{15}$	$\frac{7}{8}$	1	$\frac{1}{9}$
PERIODIC TIME or length of Planet's year	88 days (nearly 3 months)	nearly 225 days (7½ months)	365¼ days	687 days (nearly 22½ mon
MEAN DISTANCE from Sun in millions of miles	36 orbit very eccentric; distance varies from 28 to 42	68 orbit nearly circular	93	141 (varies from 12 152)
Approximate MEAN VELOCITY of Planet's motion in its orbit in miles per second	27	21	19	15
Period of ROTATION	24 hours [88 days, according to Schiaparelli]	about 24 hours [225 days, according to Schiaparelli]	23 hours 56 min. 4 secs.	about 24½ hou
APPEARANCE, etc.	Never more than 28° from the sun. Seldom visible to the unaided eye.	Never more than 48° from sun. The most brilliant planet as seen from the earth. Venus is a morning star while moving from superior conjunction (*i e.*, when in the line joining the sun and the earth, and *between* them) to inferior conjunction (*i.e.*, when in the same line, but beyond the sun.)		When nearest the earth (as in 1 is the brightest ject in the sky 1 to Venus and J ter. Spots of glis ing white are to seen at the po supposed to be caps. Irregular ches of red co are regarded as la and others of gr ish tint as wa The so-called *ca* are perhaps val inundated by melting of p snow. The "d ling" of these car seen in 1861-2, probably due cloud banks. Lockyer in *Nat* Sept. 8, 1892.)
SATELLITES OR MOONS	None yet	observed.	1 moon distant about 239,000 miles. Diameter, 2160 miles.	*Deimos* 9, *Ph* 11 miles in dia ter. Phobos revo (6000 miles awa 7½ hours.

HE PLANETS.

portion of three times the numbers 0, 1, 2, 4, 8, 16, etc , added to 4 -*i e* , to the numbers 4, 7, 10, 16, 28, miles. There is no known relation between the distances of the planets and their sizes, or masses.]

Planetoids or Minor Planets	Jupiter	Saturn	Uranus	Neptune.
bout 300 of these all planets are own, all discovered within the pre- nt century)	86,500	73,000	31,000	35,000
	1300 (1½ times as large as all the other planets put together)	700	72	90
$\frac{1}{4}$	300	90	14	17
from about 3 to arly 8 of our years	4332½ days (11 years 10 months)	10 759 days (nearly 29½ years)	30 687 days (84 years)	60,127 days (about 165 years)
224 to 270 ome of the orbits very eccentric	483 orbits	886 more nearly cir-	1780 cular	280
	8	6	4½	3½
	about 10 hours	10½ hours	unknown	unknown
Nearly all invisible o the naked eye	The brightest planet next to Venus, and the largest in apparent size (except Venus when in inferior conjunction) Flattened at the poles 3 or 4 distinct *belts*, possibly of cloud, are seen parallel to the equator	Light appears of a dull yellowish colour Flattened towards the poles girdled in the plane of its equator by a series of *rings*, which probably consist of an immense number of very small satellites	Generally invisible to the unaided eye	Invisible to the naked eye
	5 The smallest can be seen only in the best telescopes.	8 beyond the rings	At least 4, having retrograde (E to W) movement in a plane nearly at right angles to the plane of the planet's orbit	1 discovered by Lassell in 1846

matically shown in Fig. 69, it not only becomes bent out of its course, or *refracted* by its passage through the prism, but also opened out fan-like into various coloured rays, which, falling upon a screen, form a band of colours called the *spectrum*. This spectrum (following Newton, who first investigated it) is usually regarded as being made up of the seven colours, *violet*, *indigo*, *blue*, *green*, *yellow*, *orange*, and *red*, in the order given, but the various colours pass into one another by insensible gradations. When the coloured rays, before falling upon the screen, are allowed to pass through a lens, or through a second prism turned the opposite way, they close up and form a white spot upon the screen. Newton therefore concluded that ordinary sunlight is composed of many differently coloured rays, which are unequally bent, or refracted by a prism, the violet being most, and the red rays least refracted. This separation of white light into its component parts, by means of a prism, is called **dispersion.**

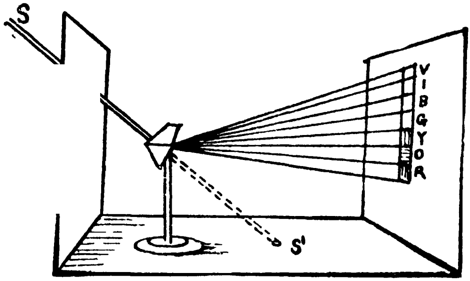

Fig. 69.

Glowing solid and liquid bodies give *continuous spectra*, consisting of a band of colours passing one into another without any break; but glowing gases or vapours, unless very dense, are found to give *discontinuous spectra*, consisting of a definite number of bright-coloured bands, or lines. One of the simplest of these spectra is that of Sodium, consisting of two yellow lines so close together that they are usually seen as one. It may easily be seen by examining the light from a Bunsen burner or spirit lamp, in which common salt is held or sprinkled, by means of a **spectroscope**, an instrument consisting of one or more prisms, and a system of lenses, which serve to magnify the spectrum and make it more distinct. It was suggested by Fox Talbot and Herschel, in 1825, that the presence of small quantities of various metals in different minerals might be recognised in this way.

2. **Fraunhofer's Lines.**—So long ago as 1802 it had been shown by Wollaston that the spectrum of sunlight was not a completely continuous band of colour, but was crossed perpendicularly to its length by several dark lines. In 1817 Fraunhofer rediscovered these dark lines and measured their relative positions; hence they are usually known as *Fraunhofer's lines.* Some of these lines are due to absorption by the earth's atmosphere, and are therefore more marked when the sun is low in the heavens, and there is consequently a greater thickness of air to be traversed, but the lines in the spectra of the stars and nebulæ are not the same as the lines in the solar spectrum, as would be the case if all of them were due to absorption either by our atmosphere or by some medium beyond it: hence we conclude that the cause must exist *in or near the sun itself.* Fraunhofer distinguished the principle lines of the solar spectrum by the early letters of the alphabet, as shown in Fig. 70, and he found that the *two yellow lines given by the sodium flame coincided in position with the double line, D, of the solar spectrum,* a fact confirmed by the more exact experiments of Foucault and of Miller in 1849 or 1850. In the latter year Professor Stokes of Cambridge gave a physical explanation of this coincidence. It had long been known that a tuning fork, or string tuned to any particular

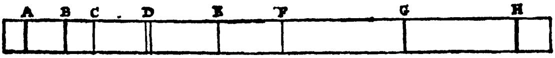

Fig. 70.

note will be set in vibration when that particular note is sounded near it. If we sing into a piano the note middle C, say (having taken the dampers off the strings by depressing the "loud" pedal), the middle C string will respond, sounding out this note. The reason for this will be apparent when we consider that each note corresponds to a definite number of vibrations transmitted by the air or other medium in which the sound is being propagated. When we attempt to cause a massive bell to swing, we find that a single pull or a series of irregular jerks will scarcely move it, whereas by timing our successive pulls to accord with its natural period of swing, thus slightly increasing its movement at each pull, it may ultimately be made to oscillate violently; in just the same way the small successive rhythmical impulses of the air set up by a vibrating body may cause a string or tuning fork whose period of vibration is the same to sound, each successive impulse serving to *reinforce* the movement already started by the previous ones. If, then (following Stokes), we imagine a screen of many piano strings, all tuned to a particular note, to be stretched across a room, it is clear that if that particular note is sounded by an instrument at one end of the room it will be partially stopped by the screen of strings, which will all be made to vibrate (yet not so violently as to sound the note loudly themselves) so that a listener on the other side of the screen will not hear the note in its full intensity. When any other note is sounded, its vibrations will not be thus absorbed, as it were, by the screen of strings, and it will be heard almost as clearly as if no such screen had been interposed. Now, Stokes argued that the same thing would apply to light: that bodies, when comparatively cool, would absorb the same light rays which they give out when incandescent, and that consequently the coincidence of position of Fraunhofer's D lines in the solar spectrum, with the bright yellow lines given by incandescent sodium vapour, proved that the *sun's* *atmosphere must contain sodium vapour, which absorbed just this particular part of the sunlight in the same way that the screen of piano strings would absorb one particular note out of the whole musical scale.*

It was not, however, until ten years later that the subject was further investigated, especially by Kirchhoff in Germany and Balfour Stewart in England. Kirchhoff found that the 460 bright lines which he observed in the spectrum of incandescent iron vapour were all represented by corresponding dark lines in the solar spectrum, thus proving that iron vapour existed in the sun's atmosphere. He further showed that dark lines not actually seen in the normal solar spectrum could be added to it by letting the sunlight pass through a Bunsen flame containing certain metallic vapours, such as lithium. This metal when used as a source of light gives a spectrum showing a very bright red line, and Kirchhoff found that on weakening the sunlight, the dark line, due to absorption by the lithium vapour, gradually disappeared, and ultimately shone out as a bright red line on the darker background. A similar *reversal* of some of the Fraunhofer lines is observed during total eclipses of the sun, when the light from the interior being screened off, the outer glowing vapours give bright instead of dark lines.

3. **Constitution of the Sun.**—It was experimentally shown by Kirchhoff that to produce dark lines, the absorbing vapour must be *cooler* than the incandescent source of light. If, for example, the light from the electric arc be passed through a Bunsen flame containing sodium vapour, the dark D lines appear in its spectrum; but if the lime light be used as the source of light, we get bright instead of dark lines, the Bunsen flame being too hot as compared with the temperature of the glowing lime to cause the required absorption. Hence it follows that the dark lines in the solar spectrum must be due to the absorption of light *by an atmosphere cooler than the luminous source.* The sun, therefore, must

consist of a white hot ball of solid, liquid, or (more probably) very dense gaseous material, surrounded by a cooler, though still intensely hot, atmosphere, containing glowing metallic vapours. According to the recent researches of Professor Rowland of Baltimore, the lines of 36 terrestrial elements are certainly, and of several others possibly, present in the solar spectrum, and he concludes that if the earth were heated to the temperature of the sun its spectrum would be very much like the solar spectrum.

The luminous visible surface of the sun (termed the **photosphere**) is seen by telescopic examination to have a mottled appearance due to bright spots or "*granules*" irregularly distributed. These granules have been variously described as resembling "rice grains" and "willow leaves" in appearance, and it seems probable that they are the tops of ascending columns of glowing vapour, which having radiated part of their heat sink again and appear as comparatively dark spots or "*pores.*" Outside the photosphere is a layer of vapours, termed by Lockyer, the **chromosphere**, consisting largely of hydrogen, and an unknown element termed *helium.* During eclipses it is seen to be of a rosy tint, and portions of it are observed to rise many thousands of miles above the photosphere, forming the **prominences** or red flames first seen in 1706, and since studied by Janssen, Lockyer, and others. Beyond the chromosphere is the **corona** (Fig. 71), seen only in total eclipses, which seems to be formed of streams of matter ejected from the sun with great velocity. Of its physical and chemical nature little is yet known; part of its light is certainly reflected sunlight, for its spectrum contains some

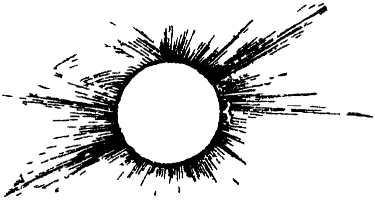

Fig 71.

Fraunhofer lines, and part may be due to electric discharges. We have already referred to the "*sun spots*" first noticed by Galileo. These spots, which are constantly changing in form and number, appear to be vast depressions (sometimes many thousands of miles in diameter), where dense vapours pour downwards to the sun's interior. This movement of recession is proved by a small shift of the lines in the spectrum (towards the red end) from their true positions, in accordance with what is usually known as Doppler's principle. Doppler (in 1841) showed that a sound should become sharper or flatter according as the sounding body was approaching or receding from the observer, for the pitch of a note depends upon the number of vibrations which reach the ear per second, and this number will be greater when the sounding body is approaching, and less when receding from the listener, than when listener and sounding body are relatively at rest. This effect may be actually observed in the case of the whistle of a locomotive engine passing through a station. Similarly in the case of light, when the source of light is receding from the observer, a smaller number of waves enter the eye in a given time than if the source of light were stationary, and the light is, as it were, *flattened* in pitch, or in other words, the lines in its spectrum (each of which corresponds to a definite number of vibrations per second) are slightly displaced towards the red end of the spectrum.

Schwabe first observed (about 1843) that the number of sun spots varies periodically, the spots appearing in greatest number about every ten (subsequently corrected to 11·11) years. There is a curious correspondence between this period and terrestrial magnetic disturbances, aurorae and "magnetic storms" being more frequent when the sun shows most spots.

4. **Constitution of the Stars.**—The spectra of many of the stars resemble the solar spectrum in giving a band of

colours traversed by dark lines; thus confirming the view that stars are suns of other systems. According to the differences in their spectra, the stars have been classified as (i.) *white stars*, like Sirius, showing strong hydrogen lines (sometimes bright), metallic lines being inconspicuous or wanting; (ii.) *yellow stars*, like Aldebaran, with spectra of solar type; (iii.) *red stars*, with banded spectra. These differences are generally regarded as indicating successive stages of an evolutional order, but different views have been held as to the most probable explanation, some astronomers maintaining that the white stars pass into a later red stage, and others that the coloured stars will become white. By the slight shift in the lines of their spectra (page 205) the motion of many stars away from or towards the earth has been determined.

References.—Tait's *Recent Advance in Physical Science.*
Stuart's *A Chapter of Science.*
Proctor, *The Spectroscope* (S.P.C.K.).
Prof. C. A. Young, *The Sun* (International Scientific Series).

Section III.—Theories of Planetary Origin.

1. **The Nebular Hypothesis.**—We have seen that our earth shows evidences of having been at one time in a highly heated condition, and that the sun's heat is probably maintained by its slow contraction; we can then reason back to a time when the sun was so expanded as to fill all the space within the limits of the present solar system: a time when our earth and the other planets had no independent existence. According to the nebular theory of Kant and Laplace, the materials which now constitute the various members of the solar system then existed as an enormous globular mass of highly heated and rarefied gas, slowly rotating about an axis. Cooling at the outside by radiation, this nebulous mass slowly contracted, and the central part became hotter; at the same time the shrinking caused an increased velocity of

rotation, the result of which was a flattening of the mass at the poles, until ultimately the globe became more like a huge disc. Near the edge of this disc the attraction of the gas to the centre by gravitation was just balanced by the repulsion due to rotation, so that the external portions exercised no pressure upon the material within, and at length, as the velocity of rotation increased, a ring or lump of the external part broke away and ultimately formed the planet Neptune. The inner portion of the nebula continuing to contract and to spin more rapidly, a second ring was shed, and then a third, and so on; these successive rings condensing to form the various *planets*, until at length the central portion of the original nebula remained to form the *sun*. In the same way many of the detached masses themselves shed rings which condensed into *satellites* or moons.

The cloudy patches of light in the heavens known as **nebulæ** (whose spectra, as shown by Huggins in 1864, consist of a few bright lines indicating glowing gaseous matter) represent, according to this theory, the earliest stage in the process of world formation, and in the great nebula in Andromeda (as shown in a photograph taken by Mr. Isaac Roberts of Liverpool) we have apparently an actual instance, on a very large scale, of some such process of cosmical evolution as is pictured in Laplace's theory. In this photograph we see a large bright central mass, surrounded by a series of successive rings of bright material (the outer ones becoming fainter), separated by dark spaces. In one of these rings occurs a brighter patch, which seems to indicate an early stage of planetary condensation, while more remote from the centre are seen luminous ball-like masses which may be interpreted as being more fully formed planetary nebulæ.

2. **The Meteoric Hypothesis.**—A modification of Laplace's theory has been suggested by Lockyer, according to which the early stages of world formation are represented

by swarms of meteorites, instead of by nebulous masses of gas. There is certainly no evidence in the solar system now of any all pervading gas, which, however rarefied, would cause some retardation in the movements of the planets, while there is evidence, as we have seen, of numbers of small solid bodies flying through space; moreover, the nebulæ themselves are regarded by Lockyer as consisting of swarms of loose stones rather than as glowing masses of gas, their luminosity being due to frequent collisions which produce enough heat to convert *portions* of them into incandescent gas. This view (first suggested by Prof. Tait) appears to be supported by a comparison of the spectra of the nebulæ with the spectra of "aerolites" heated in vacuum tubes in the laboratory. Now, Laplace's hypothesis requires the existence of a continuous mass of rotating gas, one portion of which exercises pressure upon another; if, however, the solar system was formed, not by the condensation of such a mass of gas, but by the accretion of separate loose masses of solid materials, we have no longer the requirèd fluid pressure. Prof. George Darwin has, however, shown how this difficulty may be overcome, and the two theories reconciled. We have seen that according to the molecular theory the pressure of a gas is regarded as being due to the repeated impacts of colliding molecules, which rebound after each collision, somewhat as if they were elastic balls. Now we know that meteorites do actually move with enormous velocities, and it seems probable that glancing collisions frequently occur in which part of the solid matter is very suddenly volatilised at the point of contact, and this sudden generation of highly heated gas between two stones acts like a violent explosive to drive them apart, the result being much the same as if they were highly elastic bodies. If meteorites possess in this way a virtual elasticity, Prof. G. Darwin concludes that on certain assumptions they may be treated as molecules, and that a swarm of loose stones moving with great velocity may thus, owing to their frequent collisions, behave like a "coarse gas," and thus furnish a medium such as is required by the nebular hypothesis. At various centres we may suppose the swarms of meteorites got denser and denser, owing to shrinkage by gravity, till at length the collisions became so frequent that the gases did not cool and condense again; thus, round these centres, masses of glowing gas were produced, which ultimately condensed to form the planets. The residue of the myriads of meteoric masses, which once existed, constitutes the streams of meteorites which our earth continually encounters. They are thus the mere "dregs and sawdust of the solar system." Of the primal origin of the meteoric swarms, which, according to this theory, gave birth to the sun and planets, we know nothing.

3. **The Origin of the Moon.**—According to the researches of Prof. G. H. Darwin, the history of the earth-moon system differs from that of the other planets and their satellites, in that the earth seems to have contracted nearly to its present size, before the moon separated from it. We have seen that the tides are increasing the length of our day by diminishing the velocity of the earth's rotation. Now it can be shown that the earth re-acts on the moon to drive it farther away, and we may, therefore, reason back to a time when the moon was very much nearer to the earth than it is now, and its period of revolution consequently much less. Some 56 million years ago this period was, according to Prof. Darwin's calculation, between 2 and 3 hours. The moon was then close to the earth, which turned on its axis in just the same time, its rate of rotation being almost great enough to make it fly to pieces. Moreover, tides were then produced in the molten earth by the sun, which synchronising with the natural period of undulation of the molten globe, increased the tendency to produce rupture. A little earlier than this the moon probably formed

part of the same fluid globe, which then broke into two masses owing to excess of motion. Since the moon now always turns the same face to the earth, it seems, as pointed out by Helmholtz, that the friction due to the enormous tides raised by the earth in the moon's hydrosphere gradually reduced the velocity of its rotation until at length the period of rotation coincided with its monthly period of revolution round the earth.

References.—J. N. Lockyer, *The Meteoritic Hypothesis* (Macmillan & Co.); *Atlantic Monthly*, 1888, G. H. Darwin, *On Meteorites and the History of Stellar Systems*, also, *Proc. R. S.*, Nov. 15, 1888; R. S. Ball, *Time and Tide · A Romance of the Moon* (S.P.C.K.)

NOTE.—Many of the facts and principles touched upon in this little book have been (owing to want of space) described in the fewest possible words consistent with clearness. It is hoped that readers will make use of the references for further reading given at the end of each section. These lists must not be regarded as in any sense *complete;* the more popular and "readable" works only have (as a rule) been included. Of the smaller works on Physiography, Huxley's *Physiography* (Macmillan); Mill's *Realm of Nature* (Murray); and Gregory's *Elementary Physiography* (Hughes & Co.) may be specially recommended. The last is certainly one of the best of the text books written on the lines of the Science and Art Department syllabus. Larger works are—*Our Earth and its Story*, by Dr. Robert Brown (Cassell); *The Story of our Planet*, by Prof. Bonney (Cassell); and (in French) *La Terre*, by M. F. Priem (Baillière). An excellent classified list of astronomical books will be found on pages 180 to 184 of R. A. Gregory's *Vault of Heaven* in this series.

APPENDIX.

List of Lantern Slides, etc., suitable for Illustrating the Subject-Matter of this Work.

NOTE.—In selecting lantern slides for illustrating lectures on Geology and Physiography it is important to have, whenever possible, photographs *from Nature*. Many of the advertised sets consist mainly of photographs of woodcuts and rough diagrams, many of which are hardly worth buying, as any teacher possessed of a moderate amount of skill in drawing can prepare more effective lantern diagrams by drawing, with transparent oil or water colours, upon the surface of plain glass squares previously prepared by a coating of copal varnish; or finely ground glass may be used, which is afterwards made transparent by Canada balsam. A very hard pencil should be used for drawing upon the ground glass.

Those teachers who have had no experience with the lantern should consult the little pamphlet by Mr. C. H. Bothamley on "The Optical Lantern as an Aid in Teaching (Hazell, Watson & Viney), or the larger work on "Optical Projection," by Mr. Lewis Wright (Longmans).

The following list includes slides selected from the catalogues of Newton & Co., 3 Fleet Street, London; E. G. Wood, 74 Cheapside, London; James How & Son, 73 Farringdon Street, London; J. T. Mayfield & Co., 35 Queen Victoria Street, London; G. W. Wilson & Co., Aberdeen; E. Ward, F.R.M.S., Manchester, A. Pumphrey, Stanhope Street, Birmingham. The price varies from 6s to 18s per dozen (for uncoloured slides).

CHAPTER II.—Astronomical Slides with Rack Motion (Wood, or Newton).

"Astronomical Diagrams" (8562, Wood)—Phases of Mercury; Phases of Venus; Retrograde Motion of Venus and Mercury; Rotundity of the Earth; Day and Night; The Seasons; The Tides; Motion of a Planet in an Elliptical Orbit, etc.

Portraits of Newton (7176) and Galileo (13929, Wood).

["Mechanics," Newton]—Parallelogram of Forces (2); Cavendish Experiment (16); Gyroscope (25); Foucault's Pendulum (30).

CHAPTER III.—The Electrolysis of Water should be shown upon the Screen, using a Glass Tank (Newton).

["Heat," Newton]—Expansion (2 and 3); Thermometer (9); Liquefaction of Gases (18); Snow Crystals (32, 33, 34); Comparative Volumes of Water and Steam (29).

["Hydraulics and Hydrostatics," Newton]—3, 12 and 13.

["Solids, Liquids and Gases," Mayfield]—Crystals (39, 40, 41, 42, 43, 44), etc.

The action of acid upon limestone can be shown in the glass tank.

The experiment with sulphur and iron, described on p 76, can also be partly shown upon the screen.

["Physical Geography," Newton]—Barometer (3), Winds (4, 5, 6, 7).

Cyclone and Anticyclone (9 and 10); Rainfall Map (12).

Ocean Currents (15, 16, 17).

Distillation ["Heat," 31; Newton].

(11232 to 11239, Wood) Sinter Terraces, New Zealand.

(6398, 6399, do.) Stalactite Cavern, also 4, 5, and 6 "Sections," etc. (How).

CHAPTER IV.—["Mechanics," Newton]—Pulleys (5); Lever (6, etc.); also ["Solids, Liquids and Gases," Mayfield]—10, 11, 12, 20, etc.

[232, "Heat," Mayfield]—Joule's Experiment.

CHAPTER V.—STRATIFIED ROCKS:—

(3839, Wood) Cliffs of Moher.

(3843, do.) Natural Bridge of Ross.

(3189, do.) Buckstone Rock, Current Bedding.

(178, How) Victoria Cave (limestone).

(29, 55, do.) Cheddar.

(6513, Wood) Group of Coral and Shells.

(8968, do.) Foraminifera (microscopic).

(8969, do.) Chalk (do.).

(8970, do.) *Challenger* Soundings (do.)

A very fine series of 98 slides of the Great Barrier Reef (Newton).

BASALT AND GRANITE:—

Excellent set of 32 slides of Giant's Causeway (Wilson).

Microscopic Structure of Basalt, etc., Ward's Petrological Series, especially Nos. 174, 177, 187, 287, 289, 181.

Granite Quarry, 23 of "Channel Islands" (Newton).

RAIN AND RIVERS:—

Weathering of Limestone, 35, 36, 37, 41 of "Derbyshire and the Peak" (Wilson).

4499 (Wood) Dinant.

Action of Wind, etc. (3184, 3186, 3191, 3192, Wood), "Strange Rocks."

Cliffs with Talus, 54 of Physical Geography Set (Newton).

Pot-Holes in Stream, 10144 (Wilson).

Sand Dunes, 59 Phys. Geogr. (Newton).

River Gorges, 43 and 101 (Newton); (758, Wood) Handeck Gorge.

Caverns, Stalactites, etc., 6398, 6399, 6400 (Wood).

ICE ACTION :—

[" Switzerland and the Tyrol," Newton] 1, Aletsch Glacier; 74, Glacier Garden, Lucerne; 99, Ice Pyramids; 175, Gorner Glacier.

31 and 32 of Phys. Geogr. (Newton).

(6090, Wilson) The Maddys, Loch Maddy, Roches Moutonnées.

(591, Wilson) Moraines, Glen Torridon.

(915, Pumphrey) Moraine Block, Llanberis.

(69, Norway, Pumphrey) Glaciated Rock.

(14802, Wood) Iceberg.

THE SEA :—

(2918, Pumphrey) Chesil Beach.

(17, Orkney and Shetland, Wilson) Old Man of Hoy.

Voyage of the *Challenger* Series (Wood).

(3462, Pumphrey) Natural Arch.

(3180, 453, 3003, Wood) The Needles.

VOLCANOES, EARTH MOVEMENTS, ETC. :—

(" Italy and Venice," Newton) 68, 73, 76, Etna and Vesuvius.

(" S. Sea Islands," Newton) 23, 24, 26, Kilauca.

(1, 2, 3, 55, How) Eruption of Vesuvius, 1872, etc.

(2507, Pumphrey) Arthur's Seat, Edinburgh.

(11232-9, Wood) Sinter Terraces, New Zealand.

(3155, How) Temple of Jupiter Serapis.

(2735, Wilson) Cliffs in Handa—shows bedding and joints in Torrdon Sandstone; Anticlinals—section across London Basin; Fault, near Stanton Harold; Geological Map of Great Britain, and series of Fossils (How).

Inclined Strata (4222, Wood), Lurlei Rock.

Contorted Strata (3575, Pumphrey), Stare Hole Lulworth.

(40, Devonshire, Newton), Cliffs and Beach, Clovelly.

Slaty Cleavage (11078, Wood), Slate Quarries, Llanberis.

Mountains (Physical Geography, 38 and 39, Newton), Sections through the Jura and Alps.

CHAPTER VI.—Series on "Spectrum Analysis" and on "Astronomy" (Mayfield), also Astronomical Slides (Newton), especially 63 to 76, or "Phenomena of Light" and "The Solar System" (Wood), especially 8870, 8881, 8882, 8883, 8783.

GLOSSARIAL INDEX.

Abbreviations:—L. = Latin; Gr. = Greek; Fr. = French; G. = German; E. = Element; M. = Mineral; R. = Rock; S. = Strata.

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